Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Architecture and Design
Department of Design

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Developing methods for characterizing navigational activities including Dual-Eye-Tracking method: a case-study approach

Master's thesis in Master in Interaction Design
Supervisor: Sashidharan Komandur, Giovanni Pignoni, Frode Volden
June 2020

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Preface

This work represents my Master Thesis of my studies in the Master of Interaction Design at the Norwegian University of Science and Technology (NTNU) in the spring semester of 2020; unusual times during the Covid-19 pandemic. Thankfully I was able to gather my data before academic data-gathering impossible due to the pandemic and its restrictions; thanks to all the efforts by my supervisors (Sashidharan Komandur, Giovanni Pignoni, Frode Volden) and also the Norwegian Naval Academy (RNoNA) who cooperated with us. Besides the thesis, we also managed to publish a conference paper, titled "Maritime navigation: Characterizing collaboration in a high-speed craft navigation activity", which got accepted and will be published aside the thesis at HCI International 2020 Conference in Copenhagen (Streilein et al. 2020) (see appendix A.1). The findings and evaluation of this paper will contribute to a fundamental part of this thesis. The experiment in the high-speed craft simulator was done in collaboration with the Norwegian Naval Academy (RNoNA). Such as the data-analysis was completed with the help of my supervisors Giovanni Pignoni and Prof. Frode Volden from NTNU Gjøvik.

My academic background is based on practical experience and elaborative investigation, designing and crafting prototypes to fulfill a service. This thesis was a huge challenge to my ordinarily practical work as a designer. Thanks to my supervisor Sashidharan Komandur who offered me this topic and the passion for navigation within the naval environment, I got the chance to contribute research in a theoretical and for me new way. The topic of this thesis was a huge challenge to me hence it was the first time I had to examine naval topics and navigation as well as diving into new topics such as communication pattern and dual eye-tracking. Through this thesis, I have learned valuable knowledge and experiences not only for academic purposes but also for my later working life.

15.06.2020, Tim Streilein

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T.S.

Abstract

To operate military vessels, maintaining excellent communication skills and teamwork are required to ensure the safety of the whole crew. Such a safety-critical system, like a military vessel, demands on the bridge crew to communicate and collaborate as a team to provide the safety all time during maritime navigation missions. To improve training and bridge designs for the sake of safety teamwork needs to be characterized by finding a pattern in bridge-team communication. A combination of visual observation and objective tools needs to be done to characterize communication in a navigational setting sufficiently. Dual-eye-tracking method is used to get the data from more than one crew member, assisting to characterize patterns during the navigation. Eye-tracking devices can be used to record the navigators' eye movements for a comparison, helping to identify design issues or designing training standards. Using dual eye-tracking allows researchers to characterize communication patterns more precisely than just conduct a visual observation. This case study counts as a first attempt to find a method to specify characteristics in communication, by formulating pattern occurred during navigational operations. This study was conducted in a naval simulator at the Royal Norwegian Naval Academy in Bergen (Norway), where young cadets participated. A part of the thesis was published as a conference paper (Appendix A.1) which results (Chapter 4) will be continued. The collected data from the eye-tracking devices can finally characterize communication in high-speed navigation. This study presents the potential of dual-eye-tracking as an objective tool for methods to identify and characterize communication patterns in safety-critical systems.

Definitions

AI: Artificial Intelligence

AOI: Area Of Interest

ECDIS: Electronic Chart Display and Information System

FOV: Field of view

HMT: Human-machine teaming

HSC: High Speed Craft

INS: Integrated Navigation System

MSD: Multi-Function Displays

NSD: Norwegian Centre for Research Data

OBD: Optical Bearing Device

OEM: Original Equipment Manufacturer

RNoNA: Royal Norwegian Naval Academy

SA: Situational Awareness

SOP: Standard Operating Procedure

UX: User Experience

1 Introduction

Communication is one of the most decisive key-elements when it comes to safety-critical systems such as high-speed crafts (HSC). The crew's teamwork and collaboration within the group have to be organized and precise to ensure effective communication. The performance of the operation is therefore dependent on the communication. Even though communication in a professional context is part of a social function (Holmes 2005), its main function is to work as a tool. Through communication, it should be ensured to successfully accomplish a navigational task in a maritime setting. Older research studies in maritime context from the past decades showed that 40% of causalities caused by communication problems (Quinn & Scott 1982). Even though recent research came up with similar numbers where communication was responsible for marine accidents. Research analysis by Macrae (2009)showed that 42,2% of accidents are caused by poor communication of the bridge crew (Macrae 2009, p.29). This shows the importance of communications lack in maritime settings, which are still not understood through research and has to be improved (also see Streilein et al. (2020)).

First efforts to minimize miscommunication through languages were made by the International Maritime Organization (IMO). International and national navigators need to have a common language besides their mother tongue to communicate effectively. Language has to be easy and precise to be understood in national and international waters. Therefore training communication skills became a standard in training sessions. Later in 2001, the IMO adopted the Standard Marine Communication Phrases (SMCP) to their maritime communication language set. Though the usage of SMCP the natural language got even more simplified. Any ambiguities were tried to be eliminated in the used language. Therefore a new generated English variety for maritime usage was made and to be used (cf. Hiltunen & Watanabe 2004).

Besides the invention of a non-ambiguous language by IMO, which helps misunderstandings in communication, other investigations in maritime accidents were made. McCallum et al. (2000) wrote that coast guard investigators found out that there were certain problems in common among all accidents (McCallum et al. 2000, p.389). The investigation showed that there was a lack of communication generally. Moreover, the sailors did not question others for help and often interpreted the situations on their own. Lastly, there was no verifying of information and often things were taken for granted (cf. McCallum et al. 2000, p.389)(also see Streilein et al. (2020)).

This shows the potential and the need for working communication in a maritime context. If the crew cannot communicate or understand each other more accidents will happen. This will risk human and animal life and environmental damage. Pyne & Koester (2005) explained that "[t]he need for clear verbal communications between parties in the commercial marine environment is multi faceted as the ship is the working environment, learning environment and social environment for its personnel. [...] [B]oth Pilot and crew must be able to communicate effectively to ensure safety.” (Pyne & Koester 2005, p.7).

When working as a navigator on the bridge one is not working alone. The navigator works around with a team that supports him to accomplish the goal of navigation. Salas defines a team as "a distinguishable set of two or more people who interact, dynamically, interdependently, and adaptively toward a common and valued goal/objective/mission, who have each been assigned specific roles or functions to perform, and who have a limited life-span of membership"(Salas et al. 1992, p.4).

In order to interact, crew members have to communicate most effectively. Thus, communication in teamwork plays a central role in safety-critical systems. Communication as a tool can help to increase the awareness of human errors. It might also help to understand how a situation can influence human behavior. Defining a way of good communication is the key and the future for the development of automation in safety-critical systems. In the long term, it will help to increase the situational awareness of navigators and crew members around the ship.

1.1 Keywords

`Maritime`, `Dual-Eye-tracking`, `High Speed-crafts`, `Communication`, `Collaboration`, `Joint visual`, `Teamwork`, `Navigation`,

1.2 Importance of the Problem

Problems in communication of safety-critical systems may lead to dangerous situations around the vessel, its environment and all people on board. Therefore communication, in case of safety and navigation, has to be precise and simple to minimize confusion and errors which might lead to disasters (IMO 2001, p.3). Research often identified communication as a key element in navigation. Within research on maritime accidents researches have found communication flaws in individual incidents or as part of human factors. The way of communication has shown that it can contribute positively or negatively to the vessels safety (John et al. 2013).

This visualizes the importance of communication and dialog between crew members. Moreover, Grech (2005) stated that situational awareness will be reduced through a failed communication. When crew members do not speak about relevant and important information during a mission it will cause a lack of situational awareness (Grech 2005, p.83). In another case of an accident, Chauvin (2011) explained that the communication and information sharing of the crew member would have had helped to avoid the accident. As they found out, crew members thought they would share the same representation of the critical situation. Good communication could have avoided the misinterpretation of all crew members (Chauvin 2011, p.628).

According to John et al. (2019), the communication of crew-members on the bridge can be seen as a kind of sub-genre of Maritime English. Which mainly contains navigational information through verbal communication. This exchange or communication will help to develop a shared understanding of the situation. Save navigation is dependent on a deep understanding of the situation. In case of wrong or misleading information exchange, it can cause a wrong understanding of the verbal content. Which in turn will lead to different mental representations of the situation of the ship. Then again a deficit in the right representation has the potential of wrong decision making which might lead to a safety-critical situation (cf. John et al. 2019).

Turan et al. (2016) found out in their recent study that more than 50% of the accidents in waters were caused by human error. The main reason for accidents caused by inattention, but also incapable of communication and not existing situation awareness. Human error is defined as an error that might happen due to falsely or incorrect interpretation of the situation and further on leads to wrong decision making or a not correct taken action (Wickens & Hollands 2000). Therefore, automation in safety-critical industries is an increasing try to lower human error (Hadnett 2008)). Technology-wise maritime still stays behind aviation in their bridge design (Schager 2008). The goal of automation is to improve the work and operation by lowering the workload through automation. But automation has its limitations and while it can support navigators at their routine task, but if the system fails the performance of the operator can be not enough (Onnasch et al. 2014). It has been shown that next to workload also situation awareness is lowered due automation (Pazouki et al. 2018). That means that all benefits of automation in a navigation bridge are depending on its design and the way operators are trained, to overtake in critical situations the system (Parasuraman & Manzey 2010).

Therefore communication can be a part of creating a better human-automation partnership starting by receiving sufficient training to prepare for critical situations. Communication as human-human- machine interaction has to be investigated. Earlier studies (Hareide & Ostnes 2017*a*, a) provide a good understanding of human interaction and gaze-points though eye-tracking technology in order to improve the general usability in bridge layout design. There are also studies investigating collaboration and workload, but till there are not many studies about communication between both, navigators and Assistant. Therefore, communication dynamics during an operation has to be analyzed to find more out about communication problems in safety-critical systems.

1.3 Planned Contribution

In the first instance, this research should contribute to the understanding of communication dynamics and human behavior during operating a safety-critical high-speed craft in a maritime operation. By using new technology such as wearable eye-trackers, this thesis aims to get a better understanding of communication. There is no exact definition yet which describers or considers when communication is actually effective John et al. (2013). However, a relevance of communication (correctness) does not have a relationship towards the performance in a high-speed craft context (Øvergård, Nielsen, Nazir & Sorensen 2015). Instead of focusing on the situational correctness this thesis will investigate if communication is like a tool needed and used in certain situations. Do certain situations benefit from the usage of communication and do they repeat. If communication is needed or not should be identified. By creating patterns and see how they might circle and repeated might give a better understating of the situational actions without concerning the relevance of the communication.

By using two wearable eye trackers, the thesis should aim to find out if in some cases communication is not needed to perform good performance or if communication causes worse performance. This can also relate to the mental workload which will be not investigated in this thesis and might be future work. Because communication might not always be a sign for better performance. Some situations where communication increases may end in worse conditions (Hutchins 1995, p.252). By finding standardized patterns in the future this might help understand human behavior and understanding when communication might be more or less helpful.

With that in mind, this investigation and analysis of communication patterns might be helpful for training purposes. Using these helpful patterns later on to create a method or a tool to define how communication should be in certain situations. With those supervisors in maritime vessel simulators might have this tool to validate the communication skills of crew members. In long terms, this might be increasing safety in maritime context since it was found out that still 60% of shipping accidents can be traced back to human error (Surpass 2012). Based on this a study concluded that maritime needs better solutions to train and educate in order to reduce potential accidents. Moreover, the studies imply that automated systems have to be improved based on new research, to reduce human-machine interaction (Surpass 2012).

Through involving better automation and better communication skills, a better Situational awareness(SA) can be expected. Therefore, increasing SA in the long turn will help in understanding the emergency. A new automated system might, therefore, consider the communication on a bridge to share better information to certain times which might help to increase SA. The information given by the system has still to be interpreted by the operator to actual gain SA.

Training the communication skills of crew members may a way to strengthen the SA and the mental model of the vessel situation trough communication. These patterns or results can hopefully be used to improve automation. This can be done more specifically though machine learning which became a huge impact in the industry recently. According to IBM (2017) machine learning and intelligent machines will have a huge impact and resulting a more effective human-machine interaction within the next years. Machines will make humans perform even better in my ways such as cognitive and emotional.

As a first attempt it is necessary to understand the information flow between operators based on identified patterns. Improve the shared mental modal to improve efficient and safety navigation. In long term make automation better and more flexible. Maybe communication itself cannot imply the operators performance, but maybe certain patterns can show similarities and identify if operators work efficient and perform well.

1.4 Thesis Outline

This thesis contains 8 chapters

Chapter 1: It gives a short introduction to the general topic of naval navigation in safety-critical systems. Further will be considered why bridge-team communication and collaboration is a crucial factor in navigation nowadays.

Chapter 2: This chapter will present the background and literature of studies from similar fields, such as safety-critical systems. The main topics are eye-tracking, communication, teamwork, and joint visual attention.

Chapter 3: This chapter will describe the used methodology for the data gathering to answer the research questions. It includes all the necessary elements of the experimental design.

Chapter 4: A published conference paper (Appendix A.1) is a big part of the initial analysis and evaluates the notes from the experiment. The results will be crucial for further process.

Chapter 5: This chapter will be built on the results from chapter 4 and will extend it. The outcome will be a time-series diagram for further analysis.

Chapter 6: This chapter will describe the independent analysis of the eye-tracking data. This analysis is necessary to create a communication pattern in the following steps. The chapter is divided into two parts. The first part covers the hand-taken diagram followed by the second part, which will bring all results from the hand-taken diagram together to create patterns elaboratively. It will show the difficulties of creating patterns and the dependency of audio on the basis of newly created patterns.

Chapter 7: This chapter includes a discussion of the results from the chapters to reflect on further steps.

Chapter 8: This chapter includes the results from the chapters, including the limitations of the study and future researcher.

2 Theory, Background, Existing Literature

2.1 Previous Publication

A part of the research in this thesis (Chapter 4) is a published conference paper which gets presented in July 2020 at the "HCI International 2020" conference in Copenhagen (Streilein et al. 2020). The paper got accepted with the title "Maritime navigation: Characterizing collaboration in a high-speed craft navigation activity" and is attached to the appendix A.1. The paper reflects a work in progress and presents the results made until March 2020.

2.2 Eye-Tracking

In the research field of eye-tracking and dual-eye-tracking in maritime context much prior work has been done, e.g. eye-tracker used to investigate the certain design of the integrated system. In general safety-critical systems are a growing research area of quantitative eye-tracking research studies. In the field of maritime, Hareide et al. (2016) is one of the latest researchers using eye-tracker to understand (Hareide et al. 2016) and analyze (Hareide & Ostnes 2017*a*) navigators' actions on the bridge, and further identify scan-patterns (Hareide & Ostnes 2017*b*). These studies focus on the same facilities of the Royal Norwegian Academy in Bergen using similar simulations. Nowadays the INS is a common feature of a vessel, which takes control over more complex work. Navigators used to calculate their position, but today they monitor the position on the INS. Navigators have trust in those systems and the provided data from the sensors. As for the change, Hareide et al. (2016) stated that it is important to prioritize tasks on the INS to improve performance and limit the fixations of the eye.

It seems to be a consequential issue that the instruments are taken to much attention, therefore risking accidents. The Navigators lose sight of the outside during critical phases such as the turning phase of the vessel. Using the eye-tracker they were able to identify issues, which does not include communication yet (Hareide et al. 2016).

The subsequent study by Hareide & Ostnes (2017*a*), investigates the improvement of flaws in the design interface high-speed boat during operations. Hareide & Ostnes (2017*a*) explained that the used systems are multi-functional displays that include several systems in one screen. The high-speed crafts usually use ECDIS, radar, and conning systems at the same time. These displays provide a variety of different information such as speed, position, and heading, and other data from sensors around the boat will be shown on the display. Look backs to the ECDIS are failures of the navigator's memory, caused by the limited temporal capacity. But look-backs reveal the importance of information, but it is not easy to interpret those behaviors (Hareide & Ostnes 2017*a*). This study was based on a single person's visual perception (Navigator) and reveals flaws in the design, which distracts and grabs attention during the operation.

Followed by the earlier study Hareide & Ostnes (2017*b*) come up with a way how to use the information around the bridge more efficiently. Hence the amount of information has increased due to the ECDIS, there is a need for information management. In conclusion, Hareide & Ostnes (2017*b*) came up with an organized scan pattern as they are used in other safety-critical systems like power plants. Those patterns can help to lower risks and increase safety issues. The task of turning into 4 phases got divided:

1. Preparation: Gather important information
2. Turning: Change course (focus outside)
3. Control: Gather new information & position control
4. Transit: between the turns

Using efficient block-scan will help to reduce information overload and will help to navigate safely. Besides human communication, to ensure effective collaboration humans and machines have to work together to accomplish the same goal as well (Damacharla & Devabhaktuni 2019). The issue of trust must be given to all members of the crew, which includes the machine itself. For a better teamwork dynamic, a certain prediction of future actions has to be made. Hence Human-machine teaming (HMT) is an evolving field, Damacharla & Devabhaktuni (2019) pointed out that eye tracking can effectively help to improve machine learning due to eye-tracking. A mutual goal is willing to archive the same navigational tasks. In HMT the human still has control over the task and has to understand the situation. A standardization claimed to be significantly necessary by Damacharla & Devabhaktuni (2019). There are still accidents caused by humans, therefore humans' reliability has to be analyzed as well as the machines to come up with predictions. That implies that before engineers start making human-machine-teaming better, face-to-face communication has do be clearly understood in many ways to create a system that knows how to integrate into workflow and communication of its environment.

Up to this point, eye-tracking was used to investigate an individual's eye-movements during operating within a context or environment. Macdonald & Tatler (2018) argue that gaze cueing has not considered verbal or non-verbal cues yet. Looking at each other during receiving instructions might affect teamwork, as listeners in roles condition look more often at the speaker (Macdonald & Tatler 2018). They investigated real-world scenarios compared to static interaction. Additional they investigated people's look and follow the gaze in social perception. For this purpose, they looked at the data of two eye trackers, and the recorded sound. This scenario of the experiment was rather in a maritime nor safety-critical environment but still shows how dual-eye-tracking can impact the understanding of interaction.

The study from Weibel et al. (2012) relates most to the initial research question of this thesis. Even though Weibel et al. (2012) initial motivation was to test a method that allows visualizing several streams of time-series data such as audio, video, and eye-tracking data, this study deals with the investigation of the activity dynamics in a commercial flight cockpit. This way of data collection they conducted is called digital ethnography. Just as Hareide et al. (2016),Weibel et al.

(2012) aimed to study visual attention and understand its dynamic allocation. Furthermore, this research belongs to a research of the Attention Aware System, that assesses the user's attention to create a prediction for further development. This system seems similar to an HMT, Damacharla & Devabhaktuni (2019) claimed it needs more research on years later.

To understand the correlation of visual attention and the pilot's behavior, other dimensions got considered, such as actions before and after the visual attention got analyzed. In this study investigated further common an uncommon pattern as an identifier causing visual attention. Through dual eye-tracking data, they found out that the two pilots had joint participation and shared activities (Weibel et al. 2012). This study focuses more on the dynamic allocation of joint points rather than the communication aspect but can be still seen as a milestone in the dual-eye-tracking analysis.

2.3 Communication

To elaborate communication under specific conditions and evaluate it in a quantitative approach is difficult and time-consuming, hence many factors affect communication behavior. Finding an effective way to rate communication is still ongoing research in many areas, such as in the maritime context. Earlier studies in the maritime context used recorder transcripts as easy access to create efficient measurements for naval communication John et al. (2013). By measuring information flow in bridge team communication, it showed significant correlations to different situations. Transcripts were able to be separated through clear utterances in the audio recordings, which made an average of 0.87 words per second. The communication was divided into smaller chunks or segments, helping to structure the communication. The pilot spoke almost twice as much as the shipmaster in the experiment. A formal found to get the precision of the conversation to measure the quality of the content in team communication on the bridge. As continuing research in the field of communication in maritime setting John et al. (2019) turned towards the pragmatic risk analysis of bridge team communication. They explain possible risks for a misunderstanding by using an Osgood-Schramm communication model. Depending on the kind of speech (elocutionary, illocutionary, and perlocutionary speech) quantitative and qualitative data helped to find issues. As for now, John et al. (2019) research deals with verbal communication and has not concluded non-verbal communication. In conclusion, there is still potential in miscommunication caused by non-verbal cues.

Another approach is the influence on communication by the shared mental model, which further impacts the performance. Mathieu et al. (2000) observed an increased complexity through technology, hence team members share the workload, members need to know each other mental model. Teams are effected differently and share an I-P-O(input-process-output) framework. Mathieu et al. (2000) described the framework as followed: The input includes the crew, which feeds the process in where the input gets processed. The output is described as the team's result. The output can be categorized into performance, team longevity, and member's reactions. The shared mental model will increase adaptability and teams can quickly adjust the goals strategy. The shared mental model will, therefore, help to explain and predict actions. They pointed out that the conditions are changing in safety-critical situations. Talking and chatting is not given, that is why short language is already used. Therefore a shared mental model can help to quickly adapt to each other's thoughts. Moreover, there is not a single mental model of the whole system. The models are split into many more complex tasks.

1. Crew members need to understand the technology so they can interact.
2. Crew members need a shared job/task knowledge.
3. The members need to share the same thoughts about the team dynamic.
4. The members model, which includes knowledge about the skill from each other.

Mathieu et al. (2000) pointed out that a situation with high impact is more discussed and decisions are made. The paper's method showed that similar knowledge leads to better team performance.

In a recent study, Lochner et al. (2018) tried to understand bridge team communication using SWAT and ISA measures during emergency scenarios. Those methods were used to analyze the entire team communication but also focused on the mental workload during an emergency operation. They provided some insights into emergency patterns, where the decreasing performance of a crew member indicates a high workload. Asking operators directly after each action did not work as expected, that is why the SWAT measurement was more successful. As a result, they found out that the pilot was the main issuer of communication, but the method showed just an analog and not a direct understanding of the workload. Lastly, they used EDA electrodes in a simulation to measure the workload during team collaboration. In conclusion, the measurement needs to be non-interfering (also see Streilein et al. (2020)). This is why eye-tracking becomes more important, hence workload is now easier and without interfering possible (Pignoni, Giovanni et al. 2019).

2.4 Teamwork & Collaboration

Johnson et al. (2018) investigate the effect of human-autonomy teaming through the understanding of interdependencies. They created a design and analysis tool to visualize the effect of automatizing on teams. The tool helps to understand human factors and technological factors of enhancing teaming. Through road mapping, interdependence relationships can be counted and be used for better human-machine interaction in teaming environments. In conclusion, better interaction in this experiment can be used to analyze communication in a similar way to create common patterns. A workflow visualization might help to understand certain actions of the operators. Another study of teamwork analysis in a naval setting examined teamwork on vessel bridge through conversation analysis. Bailey et al. (2006) collected the transcribed material, which is based on verbal communication from the vessel. They investigated the empirical examples of how interaction works. On normal bridges they can shout over distances and noises are obstacles, which is not given in a simulator. Not just the conversation also the interaction of the team got analyzed (bridge-team-events). As communication is not standardized and not effective enough, this study is not based on high-speed crafts, as they practice closed-loop communication (see 3.4.3).

2.5 Joint Visual Attention

The affect of joint visual attention is not new and got investigated already years ago. Since new technology like eye-tracking is available, methods could be found to create a quantitative way to measure the visual attention or in particular joint visual attention of the participants gaze in collaborative tasks. Beside the safety critical systems, there has been already research in other domains for this topic around shared attention in collaboration. According to Schneider et al. (2018) JVA has been studied before through qualitative methods only and is in the case of collaborative learning ready to quantify and collect large data sets of visual processes.

In the beginning of the dual eye-tracking, it has been used for software development, where eye trackers should help to understand software in collaborative ways. In software development has been early studies about productivity in a pair-programming setting made by Pietinen et al. (2010). Collaborative work was tracked by two eye trackers simultaneously and the outcome was a descriptive analyses. That means that the data from the eye-tracker and a verbal communication was combined and findings could been made. On step further, D'Angelo & Begel (2017) showed trough their research how communication can be improved through a shared gaze awareness. In this case they described a study of remote pair programming, where participants could see each others position of the eye on the code document. It has been shown through their method that behavior changed and communication was more efficiently. The intention was to create a better practice for collocated or a remote setting, but it can be also become a relevance in future work for safety critical systems.

Besides the development of software, interactions on new media like tabletops has been done. One of a more recent research area in visual attention in collaboration is the investigation of large scale surfaces and interactive screens has been made by van der Meulen et al. (2016). Users were supposed to solve tasks by collaborating and archive certain goals through interaction on these tangible surface. Usually small groups stand around the surface to interact with each other. Initially, one of the first novice researchers in that specific area of joint visual attention was van der Meulen et al. (2016), who investigated the collaboration dynamics through given tasks around a tangible tabletop surface using the same PupilLab eye trackers (PupilLabs 2020*b*). Using eye-trackers they were able to identify joint attention by more than two participants at a time. For the novel method the number of participants was limited to four. They created a method to find patterns of the visual attention shifting especially for large multi-touch surfaces. It was shown that individual visual behaviors over a certain period of time join the visual attention among the active users. The method from van der Meulen et al. (2016) shows the affect of joint vision on the users ability to collaborate.

A slightly different approach is the investigation by Schneider et al. (2018), who also investigates the affect of joint vision in tangible interfaces. This approach of a methodology is based on co-located tabletop interface where groups are working remotely through augmented elements. In their earlier study they already showed a correlation of JVA and a collaboration quality (Schneider & Pea 2013). The quantitative results are based on a cross-recurrence graphs, which can show how collaboration correlates with the quality of the work. With that they were able to provided results which show significant importance of JVA in collaborative learning. That means that other fields can be also profit from the research they already did. Even though the research is based on a different research area, it clearly shows the height importance of investigating the collaboration through eye-tracking. In collaborate learning joint vision attention takes an important role, therefore it can be assumed that visual attention also has its importance in other areas in a collaborative setting.

More interestingly is the research from Gergle & Clark (2011), who investigated the non-verbal and verbal patterns of language in a collaborative setup through dual eye tracking. More specifically the differences of collaborative references between stationary (e.g. sitting) and mobile (e.g. standing) users. In thesis case, the navy simulator users will be sitting next to each other. That means communication and therefore the collaboration might be different in other safety critical systems. Which means that collaborative spaces influence the later communication through the systems design.

Besides the investigation of collaborative systems based on screens, Weibel et al. (2012) is one of the first who investigated not only a full collaborative system of dyad, but also a safety critical system. In this case pilots in a cockpit of an aeroplane were equipped with eye-tracking devices and microphones. In this particular case, the behavior of JVA was not target of the investigation. More particular communication and visual attention in general was quantitative analyzed. Therefore AOIs were made and conclusions could been made trough the communication dialogues and vision attention on these AOIs. Weibel et al. (2012) was referring to a joint participation, which he describes as a construction of a shared activity through anticipation and participation of the two pilots.

Since there is eye-tracking technologies is available for research purposes it enabled researchers to create methods to measure the gaze behavior quantitatively. It has been shown that individual or only specific case research is over and many studies can be applied on across different areas in JVA. As just mentioned, there has been quantitative research on collaboration through JVA in a more visual research such as Pietinen et al. (2010) and D'Angelo & Begel (2017) did with studies about developing programming software on same and relocated screens. Other real-time tasks were made in a more collaborative puzzle-solving activity with shared gaze visualization Schlösser et al. (2015) or in real world Wang & Shi (2019). It has been shown that there is a higher efficiency in collaboration through visualized gazes of the team partners. On the one hand it has been already shown by Schneider et al. (2018) that it supports task solving in a tangible interface setting and on the other hand D'Angelo & Begel (2017) found out higher efficiency in paired programming through gaze-awareness. This gaze awareness tools help to support the JVA which is due to the efficient collaboration.

As for safety critical systems, or even more specific high speed crafts, it first has to be indicated, that joint visual attention is part of the collaboration of navigating the craft. It needs to be proved if joint vision can be made during collaboration itself and if it effects the outcome. Before to try to understand the natural user interfaces of the craft's bridge, the understanding of the human interaction in a natural setting has to be understand first. The goal of the thesis will be an enhancement of the knowledge of the collaboration within this scope. This will be necessary to develop new systems that interact with humans during the collaborative tasks or supervise novice students. Moreover it might be fundamental to create dynamic systems which are able to predict teams behavior.

2.6 Research Question

One of the important research questions of this thesis will be if communication can be used as an indicator for certain actions, based on dual eye-tracking, during operating safety-critical systems. With this study communication in high-speed crafts should be investigated and it might be possible to define patterns based on communication and joint visual attention. Using a wearable and non-intrusive eye-tracker during a routine simulation can unsure to get a better understanding of communication in certain situations and might lead to a shared mental model. First, before communication patterns can be made, communication of the crew members should be categorized into types. Those types will create a chain of types, creating a sequence. It will be investigated if those types leading to sequences during a simulation. This investigation might also be helpful to get a first idea of the dynamics in communication in the high-speed craft. Do navigators need verbal communication in certain situations to have the same visual attention that might be also seen by using the eye-trackers on both crew-members. Similar to Weibel et al. (2012), who tried to asses the user's attention on an airplane to find out more about dynamics on a flight deck. That study was concluded to create a base for prediction for further development. The result of these questions might help to design solutions for supervising simulator training and its communication.

For the study following research questions will be investigated:

- **Question 1:** Are there patterns in naval high-speed craft context which can be identified by dual-eye-tracking data?

- **Question 2:** Will the video-data of two eye-trackers provide enough insights to find communication patterns without native language skills?

3 Methodology

This chapter will explain the methods used for the data gathering in this study. The experimental design consists of seven components: Participants, Environment, Task, Defined Procedure, Observation, Interview and Questionnaires, and Data Gathering. For the data gathering, the experiment was conducted at the Norwegian Defence University College, where all data was collected. Methodically collected data includes video footage, eye-tracking data, audio data, notes, and the results from the interview and the questionnaire. At the end of this chapter, ethics will be explained as used in the experiment, so they will be ethically and legally under the Norwegian's law.

3.1 Methodology Background

The experiment in this study was in collaboration with the Norwegian Defence University College and it took place at the Royal Norwegian Naval Academy in Bergen. The academy offers several rooms for simulation purposes. Since the facilities are frequently used for internal training and examinations, the Naval Academy allowed collecting data in the meanwhile. For the data gathering, the academy provided participants who were young cadets. Distributed over two days, eight rounds with respectively two participants and one helmsman were performed (Streilein et al. 2020).

3.2 Choice of Method

The research questions in Chapter 2.6 questiones if navigational operation in safety-critical background onboard a high-speed vessel obtain pattern upon various Navigators and the Assistants on the bridge-team communication and collaboration. To investigate the question and therefore bridge communication, two simultaneous used eye-tracker (dual-eye-tracking) will be used to record and gather data from the communication during training-sessions in a high-speed craft simulator. The usage of a predefined course in a simulator allows the studies to gain high repeatability in terms of navigation scenarios, upcoming ship traffic, and environmental conditions (Streilein et al. 2020).The same simulator was used in similar studies by Hareide et al. (2016) to let participants perform the navigation. According to Hareide et al. (2016) are the requirements and challenges on both, simulator and field study, very similar as navigators need the same skill-set and situational behavior when conducting a simulation.

Additionally, the process of analyzing the gathered data is determined by the communication itself. Not only the naval communication is highly complex for outsiders, but also the lack of Norwegian language makes it impossible to sufficiently understand naval communication as a non-native speaker. Therefore the methods are leaded and weighted by the visual outcome and had to function universally to be independent on these deficiencies of language skills.

Hence dual-eye-tacking is still a new field, especially in the context of communication pattern, the performance or efficiency of the methods chosen is not guaranteed. This study can be seen as an early approach or an attempt to find patterns through eye-tracking as an example from a case study. Therefore it was necessary to collect various kinds of additional data to compare results and outcomes of the observation, notes, eye-tracking, and audio-data. That way quantitative (eye-tracking, audio, questionnaire), as well as qualitative (observation and interviews), can be used to archive a more reliable result as it is described for the outcome of triangulation (Leedy & Ormrod 2015), showing same or similar results through different methods. The research question will be supported by the coverage of multiple data sources in triangulation and is commonly used in a mixed-methods design approach to discuss a single research question (Leedy & Ormrod 2015).

3.3 External Performance Evaluation

Besides the data collecting for the thesis, The Royal Norwegian Navy (RNoNA) evaluated the performance of the participants simultaneously (Streilein et al. 2020). The main goal of this evaluation was the grading of the high-speed navigation teams, in terms of taskwork and teamwork. The taskworks represent the technical navigation skills as teamwork the expertise in communication and coordination of the team. The RNoNA base their performance score on performance metrics since these are considered as the best method to balance teamwork and taskwork connections (McIntyre, R. M. & Salas, E. n.d.). The assessment form created by the RNoNA experts considers competencies for safe and efficient high-speed navigation which are necessary for the mission (Streilein et al. 2020).

This practice is based on observation, helping the inspectors to assess taskwork and teamwork behaviors for every team in the experiment. For the route, they use the same segments with different levels of difficulty as described in 3.4.3. Teams that get a low score, based on the observation, in taskwork and teamwork in one or more of the segments, are more likely to get also low scores on the success of the mission. The effect of how the performance success the simulation will be easier to observe in harder segments (Streilein et al. 2020).

3.4 Experimental Design

3.4.1 Participants

The participants in this experiment were young cadets who were presumably in their twenties. The cadets were selected by the Royal Norwegian Navy Academy that provided 15 cadets and one staff member for this experiment, in total 16 participants. Three participants were female and therefore the significant minority of the experiment. Hence the experiment is a case study a lower number of participants is acceptable and common in such studies. As a result, a generalizing of the results will be not possible, and results will be more perspective or general tendencies of communication in this case. When considered this small number of participants as a sample, it would come close to "Purposive Sampling" Leedy & Ormrod (2015), whereas the cadets represent a typical group.

Accept of the first round, the Assistant and the Navigator got always represented by the young cadets. Since it was eight experiments (two participants at a time) and only 15 cadets, the first rounds Assistant was replaced by a staff member who had equivalent knowledge as the cadets. In the position of the helmsman was always the instructor, a helmsman from the Royal Norwegian Navy, who took this part in each experiment. At this time the cadets were already graduating students from the operational branch of the academy, which means they absolved already around 300 hours in the training simulators before the start of the experiment (Streilein et al. 2020). Furthermore, cadets are knowing this area of the harbor at the Bjorøy island very well, since it has been the testing and training route earlier. During the experiment, the cadets also absolved a performance test by the Royal Norwegian Navy. It can be expected that it has not affected the procedure or the outcome of the experiment.

3.4.2 Environment

The experiment has taken place in a simulator of the Royal Norwegian Naval Academy (RNoNA) equipped with an official Integrated Navigation System (INS). The same INS can be found onboard bridges of larger vessels such as in Corvettes or Frigates of the Royal Norwegian Navy. Other vessel types such as Submarines and Platform Support Vessels are also using the same INS, which demonstrates the huge variety of vessels using the same or comparable INS. This simulator is used to serve as part of every cadet's navigation training and education to let them learn the basics for their onboard service. This will prepare the cadets for the real case scenarios and teach them before they carry over on real bridges. As well the INS as the simulator equipment at the RNoNA are distributed by Original Equipment Manufacturer (OEM). Therefore, the setup of the simulator has a traditional order, which means that it comes with an Electronic Chart Display and Information System (ECDIS), a modern Radar, and a Conning Display. These services can be used on the Multi-Function Displays (MSDs), located in the front of the bridge. Additionally, the Optical Bearing Device (OBD) will be lowered from the top during the simulation, located in the center of the bridge. Figure 1 shows the simulator setup with the MSD seen in the front of the bridge, however, the OBD is not lowered here (Streilein et al. 2020).

As taken from Figure 1, the simulator is implemented with seven projections in the front and one directed astern. Thereby the field of view (FOV) can reach 210°for the front view and a smaller 30°for the astern, which leaves the participants in almost realistic conditions. A disadvantage might be the lightning of the projections which are still not comparable with real daytime conditions. For training purposes, on the part of the RNoNA, the radar was turned off during the operation. Therefore the participants had to use the ECDIS and Conning applications only. During the In-Briefing the participants could use additional functions, such as the Automatic Identification System (AIS). Individually teams decided on the functions they wanted to use for their training.

Figure 1: The Royal Norwegian Navy Simulator in Bergen, Norway. Positions: assistant (left), navigator (centre) and helmsman (right)

Additionally, each navigator was equipped with a stopwatch to calculate manually the speed and position of the vessel. Therefore, the OBD was needed to be lowered and got access to the Helmsman's Binoculars screen. Any lights were turned off throughout the experiment.

3.4.3 Tasks

The chosen route is identical to the earlier one by Pignoni, Giovanni et al. (2019) except the change of direction, which now runs clockwise. The starting point is the Sotra Bridge close to the RNoNA harbor at the Bjorøy island as seen in figure 2. For the same reason as earlier studies, the route was chosen since it is used for general training sessions. Moreover, the cadets participating are generally acquainted with the region around Bjorøy island.

At the beginning of the experiment, each group of participants received the navigation plan from their instructor. The used navigation plan was created internally by the instructor of the RNoNA who used the standard notations the participants were familiar with. As for the experiment, each round required two participants. The bridge team includes a Navigator, an Assistant, and a Helmsman. However, the included Helmsman is the instructor and will be deployed for all eight rounds. The first run was conducted with a staff member participating as an additional Assistant. Since 16 participants were needed for eight runs, only 15 were available at this time, consequently, the staff member became a participant. Each crew member has a different role and task to challenge during the simulation. In the following, all crew member and their onboard

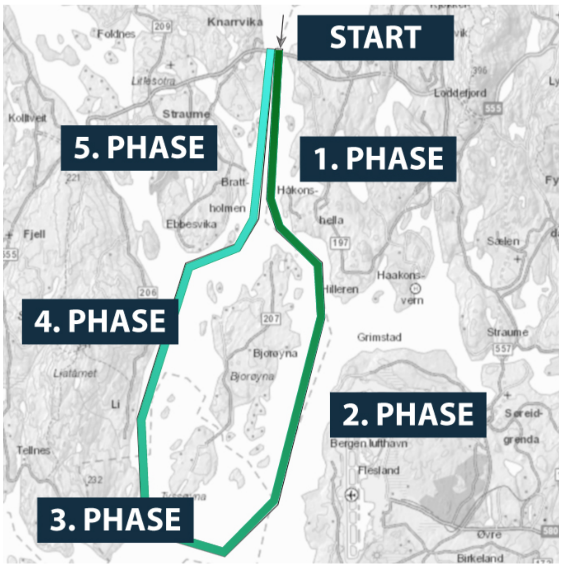


Figure 2: Bergen,Bjorøy island. Illustration of the route in the experiment.

task will be explained (Streilein et al. 2020).

1) The Navigator: As the leader of the team, he has to know the vessel's condition and location to ensure safe navigation at any time. Giving commands and orders to the crew to navigate is one of the main characteristics of a navigator. That makes him responsible for the vessel, and therefore he needs to lead the team by constantly gathering information. Furthermore, he is in charge of planning the route, which will be in close collaboration with the Assistant.

2) The Navigator's Assistant: The priority lies in providing the Navigator essential navigational information at the right time. Providing information is part of the Standard Operating Procedure (SOP) by the Royal Norwegian Navy. Further procedures (of the SOP) the Assistant has to accomplish are navigational tasks to support the Navigator's workload. This task can contain position fixes or look for critical situations.

3) The Helmsman: The active tasks of a Helmsman is to steer the vessel by using the wheel. He will take direct orders to stay in the course as speed and direction are common orders by the Navigator.

The task of the experiment starts with an approximately 5 minutes In-Briefing to prepare for the simulation. The Navigator can use this time to chat with the crew members, but will mainly work closely with his Assistant. The time can be used to plan the route and its critical parts, including all needed settings of the ECDIS.

The simulator's navigation conditions, set by the instructor, are a relatively constant speed of thirty knots of the vessel throughout the simulation. In this case, the Navigator is not in charge of changing the speed as long as no mistakes are made by the crew. All environmental conditions of the experiment are set to a morning with a clear sky and no interference. The cadets' unknown variable of pre-created scenarios will be the same every round. These situations or phases e.g. crossing ships are programmed by the instructor. The exercise will take around 25 minutes, plus around 5 minutes for the in-briefing. The instructor created five phases (5 min. each, cf. Figure 2) which differ in complexity (Streilein et al. 2020) and characterized as followed:

1. Phase The vessel starts from the baseline with simple navigation. This part will be without ship traffic.

2. Phase The route is still easy to navigate. One single ship appears - light traffic which is easy to pass.

3. Phase This part is easy to navigate without traffic. At this phase, the vessel hit the turning point and heads back to the baseline.

4. Phase During this phase, ship traffic will suddenly appear, which could cause a near-collision (actions are required). Therefore, navigation gets challenging due to a narrowing situation.

5. Phase This phase is much more complex due to is increased traffic. However, the navigation gets easy compared to the last phase. If the participants understand the situation of the traffic right, it does not require complicated actions as before.

The Navigator and Assistant are dependant on each other's information since both of them need it to achieve their task. Therefore, communication is an extremely important factor during navigation and requires close collaboration. Team members focus on closed-loop communication, which requires the receiver to the repetition of information. After the exercise, the participants will be asked to fill out the questionnaire, followed by a short interview. The de-briefing takes approximately 15 minutes to conduct (see also Streilein et al. (2020)).

3.4.4 Procedure

The experiment took place inside the simulator of the Royal Norwegian Naval Academy. The experiment set-up was placed in the back of the simulators room, while participants placed in the front towards the projection (Figure 2). The experiment was contacted over two days, in which eight rounds (1. day two experiments, 2. day six experiments) were held. The cadets were asked by the academy to join the experiment, therefore the timeline of the two days was organized by the academy. The timeline was arranged in slots of sixty minutes per group. The first twenty minutes were reserved for the in-briefing of the participants, which includes the general instructions, equipping of the instruments, and a task briefing. The actual experiment itself took around twenty-five minutes to absolve the course, followed by a short de-briefing session of fifteen minutes in the adjacent room. The debriefing was meant to have the following questionnaire and a very short interview with the participants (see also Streilein et al. (2020)).

The simulator room was big enough to include the team from the research, as well as the participants (cf. figure 3). During the experiment, the two participants, plus the helmsmen were experimenting, while three of the research-team were collecting data from the back. Besides the NTNU research, an internal performance evaluation was conducted. Therefore, another two researchers from The Royal Norwegian Navy sit in the back, observing and evaluating the participants 3.3. During the main experiment, data were collected using different equipment and tools.

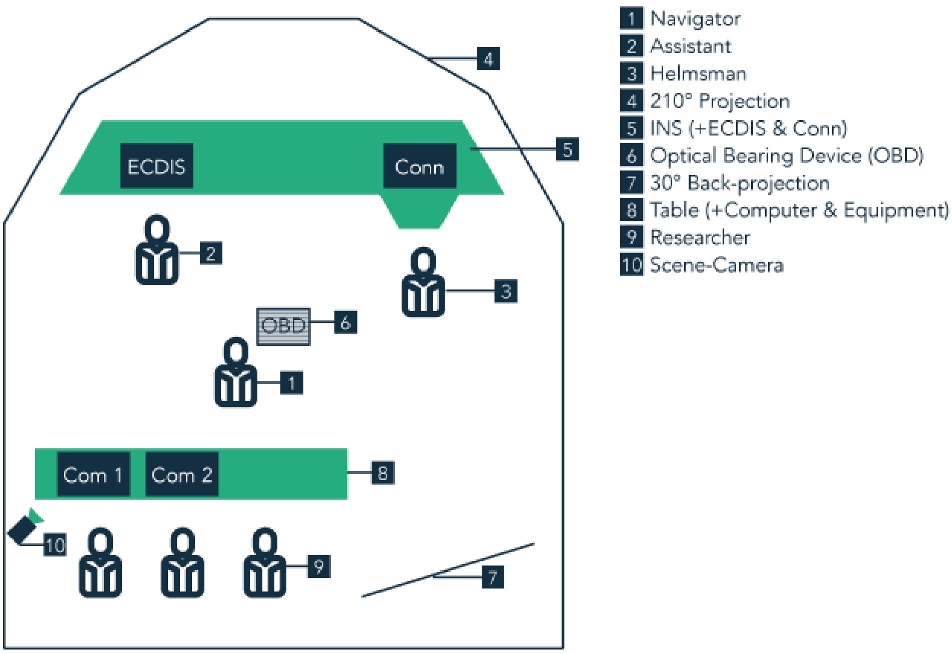


Figure 3: Overview of the simulator. Including the INS and all actors

The experiment started with general instruction and advising the scope of the experiment. Participants got informed that the performance of the individual participant is not a concern of this study and will not be judged, as this experiment was set up to detect communication patterns. Further, participants got notified of how the data will be processed, followed by signing the consent form. Since the experiment was part of an official training session, participants got told to act as they would normally.

After the short instruction, participants got equipped with an eye-tracking headset and a wireless microphone. The next step was to run a calibration of the eye tracker. At first, the Assistant who set on the left side of the room got his eye-tracker calibrated, next was the Navigator who stand in the middle of the room. This procedure was done to minimize any cable issues and to use the limited space efficiently. The calibration was done using a marker in different positions. One was holding a marker that had to be followed to increase the eye-trackers accuracy. Each eye-tracker (PupilLabs 2020*b*) was connected to one of the two computers in the back of the room. The cables were long enough to allow reliable free movements for both participants without causing any hindrance in the naval activity. At this point, the internal briefing and instructions by the instructor (Helmsman) started before the experimental simulation started. The light was turned off during the simulation.

Eye-tracking data was saved with the Pupil Capture software and later transferred to external SSDs. After every second experiment, for safety reasons, the collected data from the microphones and the scene-camera was saved also saved on the external SSD. Other recorded data, such as position logging and playback files are preventive saved for later data analysis. During the experiment, notes were taken by hand, based on observation of the participant's communication and collaboration. In the meanwhile, the computers were observed to see if the recording is running and to detect any crushes of the software or other issues. A third person checked by that time if recordings of the microphones and scene-camera have not stopped or run low on battery.

During the experiment, the participants were in the front while everyone else was sitting behind. On the left sat always the Assistant, who could choose if he wanted to sit or stand during the experiment. The Navigator always started in the middle of the room behind the OBD. The Helmsman always stood on the right in front of the steering wheel for the entire time, as seen in Figure 3.

After the experiment and recording were stopped, the de-briefing phase was initialized. Participants were asked to take the equipment off to check it for the next run and were guided to the adjacent room. Before every questionnaire, participants were instructed to fill it out as they understand the questions by using the provided color pens. Most questions asked to color a template of the course. The questionnaire was followed by a short interview. The questionnaire included questions about the route, communication, and information (see also Streilein et al. (2020)).

3.4.5 Eye-tracker and Microphone

Hence using dual eye-tracking to investigate communication patterns and information flow, each participant got equipped with an eye-tracker. For each experiment the navigator and the assistant got equipped with the Pupil Pro eye-tracking glasses (PupilLabs 2020*b*). Each device will record an egocentric video from each participant and additionally the video of the right eye for pupil-tracking purposes. The eye-tracker is capable of recognizing eye-movements by the reflection of the iris using infrared technology to map later into the egocentric video. During the experiment both participant's eye-tracker recorded at the same time and the data was stored separately on a computer for each participant. Since the wireless feature of the pupil lab software did not work reliably, both eye-trackers got each wired separately to a computer. In this case it was ensured that the length of the cable has a sufficient length leaving the participants to move freely as possible in the simulator. By actively observing and guiding the cable during each experiment the risk of tripping on the cable was depleted (Streilein et al. 2020). The pupil labs eye-tracker software has not very advanced software but its design is significantly minimalistic. Therefore the small camera and its light frame can be worn subtly during the experiments without interfering with the participants' actions and behavior, which is more important.

Besides the pupil lab's eye-trackers the audio of the communication was recorded of each participant. Participants got equipped with a Sennheiser 2000 wireless microphone transmitter which could be easily put either on the belt or in the pocket. The cabled microphone was attached to the collar where it does not interfere with the navigation. The Sennheiser transmitter sent the audio to its transceiver, which was attached to a Zoom H4N audio recorder. Thus it was possible to receive and record audio directly without having more cables reaching the participants. Furthermore two receivers were connected to the Zoom audio recorder at the same time. Each participant transmitted the audio on a different channel of the Sennheiser transmitter. In every experiment the Assistant was connected to the left audio channel and the Navigator to the right audio channel of the Zoom H4N. By recording the audio in stereo Wav-format, it enabled to record synchronized in a single audio file. Since the setup was wireless it was easy to monitor and control the recording besides the eye-tracking.

The third source was a GoPro Hero3 camera which was used as a scene-camera and placed in the back left corner of the room (Figure 3). This camera captured the activities from a distance. The wide-angle camera enabled to record the complete bridge accept the back-projection. This will help to identify any later movements of the participants or inaccuracies in the eye-tracking video stream. As a backup it recorded the audio with the internal microphone which is normally not recommended. For each experiment a number and the file name were written down for the eye-tracking data, audio-recording and the scene-camera to allocate the participants back for later analysis.

Before each experiment started a calibration test had to be conducted as it was recommended in the created experiments protocol (see Appendix A.2). The Assistant got first calibrated before the Navigator due to the limited space in the simulator. The calibration process followed the instructions of the pupil labs manual (PupilLabs 2020*a*), using the manual marker guide. Each participant had to follow the marker in a certain frame until a usable accuracy was given. As a result, the calibration was not always satisfying which resulted in lacking accuracy, which was probably caused due to the low light conditions in the simulator, even though the calibration was conducted under brighter conditions (see the results of the calibration in Appendix A.3). The previous testing under better lighting conditions has not shown any problems. After the calibration phase, the participants started with their in-briefing when all instruments started to record and the experiment started as is was noted in the storyboard. After the experiment electronic devices got unequipped and prepared for the next experiment. The checking includes servicing the electronics to look for fully charged batteries and free space on the memory sticks before going on.

3.4.6 Notes

Taken notes are one of the most crucial and easy data-gathering for later analysis. By taken notes, one is the observer and be able to note everything important a camera might not be able to. The information noted down will be crucial to understand the interactions between all participants during the operation. Hence the video material will be already a highly rich source of information, it will be most likely that this information can be difficult to interpret afterward. That is why it is even more important to take notes during such an experiment to have insurance in case of data loss. The great ability about taking notes as an observer is to be able to go over instantly progressing with the data analysis(Courage et al. 2015). Those notes were therefore used for the following interview in the debriefing (see also Streilein et al. (2020)).

As soon as the participants got equipped with the instruments and the eye-trackers were calibrated the observation including taking notes started with the briefing between the Assistant and the Navigator. During the experiment, it was important to capture particularly crucial information since the pace of the communication was very fast and note-taking had to be efficient at this time. Therefore a shorthand and a template were developed ahead to note all key elements much faster. The template helped to remind of common behaviors and writing down full notes which are later comprehensible, getting also the notes organized straight away (Courage et al. 2015). The created template provided a timestamp, initiator of the communication, the type of communication (non-verbal/verbal), and the outcome, which should be noted down for each observed activity. Even though the template helped to organize thoughts and observation, not all aspects or activities could be fitted perfectly into the template, making it easier to focus on the communication to keep track of the nuances. The active note-taking and observation ended by reaching the last point of the route where the helmsman announced the end of the simulation.

The notes from the observation were mainly used for the first analysis in Chapter 4.4 to contribute to the first initial analysis to get a feeling for the situation and the collaboration in general on the bridge. Those notes helped to interpret the data within the timestamps and identify the same and different behavior upon the cadet's navigation skills to finally come up with a first segmentation of the navigation.

3.4.7 Questionnaire and Interview

For the experiment, a questionnaire and an interview were planned as part of the debriefing to get broader information and understanding of the background and self-assessment of the information-flow on-board the bridge communication. The questionnaire catalog was built upon 4 distinct questions asking the participants to mark their answers by a provided color scheme. The following are the basic asked questions from the questionnaire given to the participants (for more details see Appendix A.4).

1. How frequently do you require information from your teammate?
2. What is your primary information source during the navigational course?

3. Did you receive sufficient information during the navigational course?
4. Mark critical section where communication is particularly important.

The questions were formulated regarding information flow in navigational procedures, to get information about communication routines. All questions came with a color scheme and the same map creating consistency for later analysis.

The last question of the set allowed the participants to provide feedback in the form of a given space for answers. Each section of a question provided one page with the question itself, together with its instructions to answer it, plus an extra page with the corresponding map. The course on the map around the harbor was represented by a white line. The white line was asked to be colored in the question. The questionnaire came in an in advance prepared DIN-A4 format.

After the participants completed the experiment in the simulator, they were asked to take off the equipment and were free to participate in the questionnaire. All participants in the experiments accepted to take the time to fill in the questionnaire afterward. Therefore they got invited into the neighboring room where two tables for each participant were already prepared. All printed questionnaires and the needed pens were already at its place. Participants got instructed to follow the instructions as written on the paper and use the provided colored pens as it was asked in the questions. The participant number and role had to be written down on the first page. As already mentioned, each question consisted out of two sites, one with the questions the other with a map where they had to color the route. To make it easier a copy with all questions were separately provided so they were able to look at the questions at any time without looking back and forth. Both, the Assistant and the Navigator, received identical questions.

To fill out the questionnaire the participants got as much time as they required. It usually took about 10 to 15 minutes to complete the questions, leaving some time to have a short interview based on the previous simulation before the next experiment was going to start.

The final interview helped to get a better understanding of the user itself and to get the chance to ask questions which came up during the navigation in the experiment. The interview will be seen as an informal discussion based on taken observation notes. Since it has no prepared questions, the prior questionnaire should answer the most important questions quantitatively. Therefore the form of an unstructured interview was chosen which is more similar to a conversation (Courage et al. 2015). The asked questions of the interview were formulated in a way participants could answer in an extant they wanted and provide the details as they wanted. This helped to talk about various topics in the navigation aspects in an open-ended way. Furthermore, the flexible structure allowed situational changes that occurred by different approaches of the experiment upon the teams. By not knowing what answers can be expected made an unstructured interview very useful for this situation, even though the set of questions and consistency are very low at this point. The interview was conducted as a casual face-to-face interview, while notes were taken by hand on paper. It was most common to ask about certain non-verbal communication patterns and about standard procedures which appeared certainly often, helping to understand the navigation from the cadets' point of view. The interview will not be part of the evaluation or analysis as it was conducted to help understand the cadet's behavior.

3.4.8 Data collection

To identify and create a way to find patterns in the naval communication during a navigation simulation of a marine vessel various kind of data was collected and step-wise analyzed. Qualitative data was first taken in the form of observational notes (see Streilein et al. (2020)) and further processed by manually matching to get new results. Further data was taken through audio recordings, video footage, and eye-tracking which provided rich data to analyze in many ways. Therefore the eye-tracking data was used to determine AOIs of the participants and create deviations and assumptions statistically about the cadets' communication. More quantitative and qualitative data was accumulated by the answers of the questionnaires and the interview in the debriefing. The qualitative part was accumulated through the comments on the questionnaire and the feedback through the unstructured interview. That led further to insights into the participants' self-reflections and opinions. The questionnaires were paper-based and had to be digitized later on.

Hence paper-based questionnaires were hand out to participants, avoiding misunderstanding wording or misleading questions is substantial. The questionnaire was designed and improved through the discussion with the supervisors and ran through a short user testing to become self-explaining and doable without any further questions on the side of the participants.

3.5 Ethical and Legal Considerations

The project was transmitted to the NSD (Norwegian Centre for Research Data) for approval (see assessment in Appendix A.5. The submission included all relevant and important documents which were used for the data gathering process, such as the equipment, questionnaires, and interview procedure. Researchers are required by the NSD to declare all types of data that are collected during the studies experiment. Furthermore, precise information had to be provided in how the data will be saved, protected, and how it is going to be analyzed to protect participants' privacy later on.

Before each experiment, all participants got informed about their rights and confidences verbally and received a printed version of the consent form (Appendix A.6). The consent form summarized the project and the procedure of the experiment they are going through. It further informed the participants about their rights, as they could quit anytime and claim to be deleted from the data. This also included all censorship of participants' private data such as faces from the video and eye-tracking data. As for the data analysis, participants became anonymous through acronyms of the position and numbers. The actions and steps made to protect the participant's privacy in this study can be considered as ethical and legal under Norwegian law.

4 Initial Analysis: Notes

4.1 Introduction

After the experiment was finished, the collected data was ready to be processed further. However, analyzing the notes from the observation will bring the first results very fast, to gain impressions and knowledge about navigation and its communication changes. This is a crucial step as it is the first examination of the experiment. Therefore the analysis began with the examination of the notes instead of the data from the video and eye-tracking footage. It should be mentioned that this chapter will highlight the way the early results from the conference paper of Streilein et al. (2020) got evaluated, as it is a crucial part of this thesis and intervene with it (Chapter 2.1). This chapter will show how the initial segmentation of the navigation was evaluated as the results will overlap with the outcome of the conference paper (Streilein et al. 2020).

To gain a greater picture of the activities, which happened during the experiment, the total of the 8 simulations led down site by site. In the first step of highlighting the important parts to leave unimportant notes out was necessary helping to sort the notes to its core. This procedure was followed by restructuring the notes by time to cluster notes throughout the participants. This step is not an issue, hence it can be assumed that the participants needed approximately similar time to finish the simulation (see chapter 2.1 or Table 6). From that point, the passages could be organized helping to find similar behavior within the participants. These behaviors and activities were marked with different colors to distinguish and additional notes were used to categorize. This involved determining who said and has done something (Assistant vs. Navigator) in certain situations. Shortly after first fragments became clear and certain behavior repeated throughout the experiments. Finally, the map including the route got involved to determine defined segments after all.

4.2 Method

This analysis will give a detailed description of the observation notes' outcomes, which were taken during the experiment. This will be built up the fundamental understanding of the communication, help to get familiar with the data. The initial observation will be necessary to break the experiment down into chunks or repetitive patterns. This will be taken as an initial step before examining the quantitative data from the eye-tracker. This analysis will be handled as an attempt to see how the phases and patterns can be detected through pure observation. Moreover, conclusions can be made to investigate in a more specific and focused way. The five phases the instructor created for the simulation (see Experimental Design: 3.4) are not considered at this point. These new created phases are the outcome of changing communication during the simulation, but they do correlate (Streilein et al. 2020).

4.3 Results

Phase 1: In-Briefing

Before each experiment, the Assistant and Navigator were supposed to plan their upcoming route by creating an individual strategy. The navigator and the assistant are conducting a short in-briefing. Other than the experiment itself, this in-briefing seems more unstandardized as specifically the communication part. Each group has its way of going through the in-briefing phase. The route will be inspected and difficult situations will be planned. Therefore, it is required that the system has to be set with necessitated settings. As mentioned by the participants, the crew does not want to apply the complete set of helping- and guidance-settings for the ECDIS. All crucial information has to be balanced. Otherwise, it might lead to an unconscious reliance on electronic helpers. Applying all settings to the ECDIS would lead to information overload and threaten the operation. Information overload would respectively increase the mental workload of the assistant during the exercise. The aforementioned would lead to slower information processing and ultimately lead to problems and risks to the whole crew. This makes the briefing phase as crucial and important as the navigation itself. At this point, it should be mentioned that the route is already known very well by the participants and one can assume that they already know which settings might be optimal.

Phase 2: Initiation

The initiation phase starts by checking the systems and crew's status on behalf of everyone. In this phase, the Navigator seems so start the process by going through the important parts and ask Assistant and Helmsman for feedback. This happens almost always verbally when the Navigator standing in the middle of the bridge. Sometimes the Navigator also steps for and checks the instruments from the Assistant, the bridge OBD as well as the binocular of the helmsman. Verbal feedback is given through standardized sentences for naval bridge communication as acquired at the academy. Feedback on status such as "Det ar god" (That is good) or unofficially "yap!" will be heard during the entire experiment. In some cases (exp. 3;5) the Assistant designated concerns by non-verbal clues. As for the first case (exp. 3), the Assistant turned his head to get the attention of the Navigator, who then stepped forward. In experiment 5 the Assistant explicated something important on the instruments by pointing on it. In both cases, the navigator reacted to the non-verbal clues and must have seen those. It might be possible that there were besides non-verbal clues other verbal clues that led to the Navigator's action. Those clues will not be considered. As for the experiment 7, the navigator and assistant looked booth outside at the same spot. The following look on the ECDIS might lead to the assumption that both have had a joint vision.

Phase 3: Planning 1

The first initial phase led quite fast over to the planning phase. It generally consists of checking new coordinates to organize the upcoming turn. In this phase, the Assistant provides information and coordinates from the instruments which will be repeated by the Navigator. At this point, mostly verbal communication is conducted. The assistant's job is to provide coordinates by constantly looking at the ECDIS. In the meanwhile, the navigator can watch out and check if the provided coordinates correlate. Sometimes also the Assistant tries to look outside as seen in experiment 7. There had been three distinct scenarios that lead the Navigator to look at the ECDIS. In experiments 2 and 6, the Assistant himself seems to need confirmation or feedback. The Assistant in experiment 6 got seen by the Navigator. The Assistant was able to show something important by pointed it out (non-verbal). By pointing on it the Navigator was able to provide feedback. Other than this, the Assistant in experiment 2 first seemed to be not seen or ignored by the Navigator. In experiment 4 the Navigator himself initialized to point at the ECDIS. That lets one assume that cooperative actions at the ECDIS can be initialized by either the Assistant or the Navigator. Lastly, the Assistant of experiment 5 pointed something out on the ECDIS even though there had been an initial verbal silence.

Phase 4: Turn 1
The first turning phase lets the Navigators overtake the talking and commanding on the bridge. His commands are often directed towards the helmsman. The Assistant will be less talkative at that moment. In most cases, the Navigator generally acts very actively during the turning phases. He observes the bridge and the outside environment continuously. Even if he is not stepping forward to the ECIDS he will still try to check it from the back. Infrequently some navigators checked the back-view-projection of the vessel. The Assistant just rarely talked to the Navigator at that phase. In general, a rise in the voice volume was noticeable, probably due to the tension of the situation. Especially when all participants tried to talk simultaneously. As mentioned by the participants, the navigator holds the highest position and gets, therefore, a priority when talking. Everyone has to listen when the navigator interrupts. During the first turning, there has been also phrases where nobody talked and it seemed quiet for a moment.

What happened to be more unusual was the fact that the Assistant looked way more outside during that phase. According to the participant's statement, the navigators can ask for active assistance during the in-briefing, as happened in experiment 6 and sporadically 7. In this case, he was directed to move the focus on the outside and help to pinpoint difficult situations. Assistants try to be more supportive by planning the next steps for the navigator. As for experiment 6, both participants were originally trained navigators, but one had to interact as an Assistant. Beneficial, the participant might be better in understanding the navigator's needs for certain situations as mentioned by Mathieu et al. (2000), who pointed out, that the shared mental model will be enhanced by shared knowledge of the task, which in turn can improve the communication (cf. 2.3). Occasionally the Navigator stepped forward to look at the ECDIS. As taken from the interview, one needs to clarify the situation. During the inspection of the ECDIS, at least one of the crew members has to observe the outside for safety reasons. The navigator always delegates the responsibility to someone to keep observing.

Phase 5: Planning 2
Planning phases can be identified by easy and stable navigation. The crew has time to plan the next actions such as an upcoming turn. Identically to the first planning phase, the Assistant provides information for the navigator, who will then coordinate while looking into the OBD

and repeating. Occasionally the Assistant raises his voice so the navigator can better understand important information. Most of the time the Assistant looks on the ECDIS while the Navigator moves freely to observe.

During the second planning phase, the Navigator seemed to ask the Assistant for the new situation. The Assistant gives positive or negative feedback by pointing (non-verbal) on specific parts of the ECDIS. This has been observed three times (exp. 1,6,7), comparable to the first planning phase. Additionally, other experiments (exp. 3,8) showed the same situations without the non-verbal communication. During this confrontation, some Assistants looked outside (exp. 1,6). In experiment 5, a specific situation of joint attention between Navigator and Assistant happened. Assistant and Navigator were looking at the same situation, just one was looking outside and the other on the ECDIS.

Phase 6: Turn 2

This is the first turn of an upcoming two consecutive turn. The end of the second turn constitutes the midway turning point of the route. Again, navigators perform more actively in the turning phase. While commanding the navigator's voice is risen and more active. As in turn 1 before, the navigator moves around the bridge to check the situation and command the helmsman. In the meanwhile, a similar pattern as seen in turn 1 of Assistants behavior can be identified. The Assistant watches again the outside for critical situations (exp. 4, 6, 7) instead of observing the ECDIS. Moreover, situations with total silence have been found in half of the experiments (exp. 3, 4, 5, 8). In seldom cases, the Assistant pointed at something on the ECDIS or tried to make eye-contact but got ignored.

Phase 7: Planning 3

The third planning phase is considered as the short phase between the two consecutive turns. The Navigator notices the new situation, while immediately the Assistant provides new coordinates for the following turn. It is noticeable that the navigator steps often forward to the ECDIS to receive additional information. Looking together on the ECIDS and pointing things out (non-verbally) helps to prepare for the upcoming turn. As usual, the Assistant provides the coordinates to the Navigator who repeats them for confirmation. In the meanwhile, the Navigator also addresses the helmsman and provides feedback such as “Det ar god”. In two incidents the assistant pointed out a situation outside trying to make the navigator aware of a dangerous situation. In another case, the assistant reminds the navigator only verbally about the dangerous situation, which seems inconsistent. As earlier, there was a situation where the assistant and navigator deliberated over a situation apart from what they looked at (screen and outside). Another occurrence showed misleading hand signs (exp. 2) by the Assistant, which can be rated as an unconscious behavior, as the participant of experiment 3 stated in an interview, that this kind of hand movement just used as a habit and have no further meaning. In a different interview, a navigator stated that navigators, in general, do not look at any kind of non-verbal communication clues. All important information is supposed to be communicated verbally.

Phase 8: Turn 3

This turn does not convey to be a complex task for the crew. The general impression is less communication and more starring outside, as it was in experiments 3 or 7. The crew was looking outside in the same direction while having little talking, which might imply joint visual attention.

Even though it was the turning phase, there had been situations where both observed and discussed something on ECDIS (verbally). In a few cases, even the Assistant pointed (non-verbally) at the ECDIS to discuss the situation, which happened usually in the planning phase.

As in the previous turns, the Navigator still performed more active, looking extensively around, including the back windows shortly after the turn has finished. Further, the Assistant's active help was noticeable as he looked outside and seldom at Navigator's activity. In unusual cases, communication seemed to become a bit bland. During less active passages, some Navigators used noticeable more non-standard of naval communication as they simply responded with "Yes" or "Yep". Compared to the study of Hareide et al. (2016), the ECDIS does not catch the attention of the Navigator significantly, which can be due to a different way of navigation. At least one person on the bridge has to look outside at all times during the navigation as standard procedure.

Phase 9: Planning 4

The next planning phase 4 started with the Assistant providing new coordinates and information exchange. In one of the experiments (exp. 8) the Assistant staid quite in the beginning until heading towards the next turn, where it got lively again. As in all other planning phases the Navigator repeatedly looking his watch and talking to the helmsman, often confirmed status by saying "Det ar god".

Frequently observed actions by the Navigators are asking questions towards the Assistant or observing outside. After doing that they stepped in most experiments forward (5 times), in some cases (3 times) the Assistant points (non-verbally) out critical situations on the ECDIS, consequently, the Navigator sees it and comes over. Followed by the previous turn 3, more non-standard communication ("yes" and yap") in a few cases remained. As seen in experiment 6 the Assistant informs the Navigator about the situation on the monitor probably because he has seen a small ship crossing by. Consequently, both are looking outside to double-check the information from the monitor. In experiment 7 the Assistant a similar action happened, where he pointed (non-verbally)on the ECDIS and further looked outside, where he points (non-verbally) on the actual ship. Despite that, the crew in experiment 6 were surprised by the ship and handled the situation differently. During the planning phase 4, it occurred noticeably often that everyone was looking outside (exp. 3,6,7) simultaneously, even though the Navigators checked the OBD at that time.

Phase 10: Turn 4

The last turn is different from the others beginning with a challenging situation. Immediately a small ship appears behind the cliffs leaving the crew with no time to act and try to maneuver the vessel around it.Subsequently, a container ship traverses the route so that the crew has to initialize a recalculation of the planned tour. In the meanwhile, the navigators get challenged with multiple tasks and need to find ways to navigate the vessel safely while calculating the new route. In total, the previous and following phases show less defined transitions making them merge into each other. When the small ship appeared, participants behaved differently, as it is mentioned in the previous planning phase.

In one of the cases, the crew did not recognize the situation fast enough, which left them no other choice than to abruptly stop the vessel. This can either indicate a problem in the setup or a lack of communication. In most experiments, the small ship was recognized early enough, and the crew was able to pass safely. Then the crew looked almost always outside to see the ship passing by, while nobody was talking. Later, it seemed like the Assistant watched outside much more frequently and became more active knowing there can be more challenging situations. As soon as the container ship appeared right after the turn, the Assistant pointed in several cases on the ECDIS to inform the Navigator of the upcoming situation.

Phase 11: Arrival

Finally, the crew got quiet again and more relaxed. This is indicated by the navigator, who stays in position behind the OBD, repeating the Assistant's coordinates. It is noticeable that everyone looked outside due to mild traffic. In some cases, it happened that the navigator still needed to check the ECDIS, and asking the Assistant for the situation.

Situations without any verbal or non-verbal communication increased, even though there had been situations (exp. 7) in which the Assistant pointed at passing ships. Occasionally the Navigator appeared still very active right after the challenging part of the route and stayed close to the Assistant to look on the ECDIS.

4.4 Conclusion

As earlier stated in the first results in the conference paper by Streilein et al. (2020), imprecise communication patterns can be identified through the taken notes. The notes can indicate a standardization in the naval bridge communication and procedures, as they were strictly taught at the academy. However, some situations showed an increase in non-verbal communication. This will be frequently used to analyze upcoming situations and supporting standard verbal communication. Occasionally the participants used non-verbal communication to pinpoint dangerous elements on the ECDIS or the environment. It often is accompanied by physical movements of the Navigator e.g. stepping for to the ECDIS/ windows on the bridge. These actions have to be linked to outline the communication pattern later on. Since both participants look at the same spot, they are using non-verbal actions to make sure that they talk about the same situations and elements. As described in the phases, other actions such as lightly head movements towards the crew-member or eye-contact might be used for other purposes, such as getting attention or a conformation. The results of the paper have been summed up into a compact table of recurring sequences (Table 1) by Streilein et al. (2020). Therefore individual planning phases and turning phases got linked together since they share certain similarities. Besides the Briefing-Phase, the experiment got organized into four recurring sequences: Initialize, Prepare, Turning, and Arrive.

Table 1: All observed sequences including the repeating patterns of (N.: Navigator; A.: Assistant)(Streilein et al. 2020)

Briefing	**Initialize**
ECDIS gets inspected Situations are discussed Non-verbal actions to point out situations Set the system and settings e.g. AIS	Check status of everyone N. initialize and takes over the lead Everyone stays in their position Using non-verbal cues (e.g. pointing and look back) A. and N. look often outside
Prepare	**Turning**
A. provides coordinates from ECDIS, N. replies N. uses the Conn and checks other instruments. N. looks outside mostly A looks outside or on ECDIS A wants attention (by pointing or turning head) A. points out a situation (outside)	N. commands the bridge (actively walks around) The voice rises often A looks more often outside and at the N. N. looks together at ECDIS with A. N. mentions s.th outside (both look and discuss) Rarely A. points at the ECDIS (4th turn)
Arrive	
N. mostly stays at middle position Everyone looks mostly outside Non-verbal communication rises A. and N. still discuss situation on ECIDIS	

The observation results by Streilein et al. (2020) give some initial insights into the communication of the naval bridge team. These observations are still based on subjective and qualitative data, which reflects the communication from a one-dimensional perspective. The notes have no completeness of contents and can be hence just counted as an early lead direction. To manifest the observed patterns, further analyses of the data are necessary. The collected data from the eye-tracker, video recording as well as speech analysis will be used as a reference for later comparison analysis. The eye-tracking data will enable to set Areas-of-Interest (AOI). The AOIs will further help to identify overlapping gazes, more specifically any joint vision (JV) or even JVA during the experiment. A speech analysis might help to integrate even more factors into the creation of patterns and to detect smaller nuances. As to proceed on the assumption that the content of the conversation does not correlate with the performance of the crew members (Øvergård, Nielsen, Nazir & Sorensen 2015), the content itself will be ignored for now.

5 AOI-Time Series Analysis

5.1 Method

5.1.1 Defining Areas of Interest

First the route was roughly separate into smaller phrases: Initialize, Prepare, Turn and Arrive (Table 1)by Streilein et al. (2020). Since knowledge is missing about navigational tasks and general language barriers, breaking down the footage step by step will help to overcome those problems. After the separation of the route for both, the Navigator and the Assistant, defined AOIs have to be determined. By inspecting the outcome of the video footage and compared with the taken notes from the experiment, 7 distinct AOIs have been defined:

1. **Outside** Looking at one of the 7 front projections
2. **ECDIS** Monitoring position, map, coordinates, and setting
3. **OBD** Checking the coordinates on the display above and looking through it
4. **Stopwatch** looking at the stopwatch for calculations and positioning
5. **Helmsman instruments** looking at one of the instruments of the HM (e.g. Binocular)
6. **Back Projection** looking backwards
7. **Others** all non-definable areas

Those defined AOIs are role-specific, as the OBD and the Stopwatch are specific instruments used only by the Navigator. Some of the AOIs, such as the Outside, ECDIS, and Helmsman instruments are defined very vaguely and imprecisely. For now further splitting of AOIs is not crucial due to its already existing complexity. Depending on further research and analysis splitting the AOIs into even further defined and specific areas will be inevitable. That means that the data at this point will not be able to tie joint vision to the vague defined AOIs. When both participants look outside it does not imply that they look at the same area. In terms of a joint vision, those fields have to be revised to get a higher value out of the data for joint vision proposes. In any case a graphic about joint vision has been made and can be seen in the Appendix A.12. This will not be discussed further in this thesis.

Figure 4: Assemble: Up = Eye-tracker incl. eye(R)+ gaze-point (Left - Assistant; Right - Navigator); Below = scene camera (GoPro)

5.1.2 Data Analysis: eye-tracker

To effectively analyze the collected data, several data streams have to be analyzed simultaneously. Such as Weibel et al. (2012) did with their own developed a program for organizing this kind of data streams, in this case, a simpler solution would do it hence only video footage will be evaluated. To analyze audio, digital notes, and the video footage all together such a data-stream program would have a high impact and advantage. For that purpose, the three data streams, one from the scene camera and two from the eye-tracking devices, got assembled into one stream as seen in Figure 4. Additionally, the footage was accompanied by the audio recorded by the wireless microphones. This video montage was made for each of the eight experiments. Each montage starts right after the in-briefing when the navigator officially begins the navigation and it ends with the reaching of the last point of the route. In general, the total time of each montage is about 25 minutes.

For the assembling of the statistics, the data was collected at a one-second interval. By going through the video footage, second by second, the accuracy is limited. At this stage however the accuracy of the data sets is fine hence the eye-tracking data itself is not optimal and underwent partial optimization through the interpretation of the situation. This process was also necessary since the software by pupil labs indicated that the results (Appendix A.3) of the eye-tracking during the experiments were not optimal and had some issues. These issues might be often due to the low light conditions in the simulator which caused initial problems during the calibration of the devices. The previous testing under better lighting conditions has not shown those problems.

As a result two recordings out of the 16 were unusable for further analysis. The affected recordings belonged to the navigators from the experiment 6 and 8, where faulty eye-tracking occurred and the eye-tracker failed to record at all. That reduces further analysis and usable sample to six experiments. A future experiment in this field using eye-tracking technology needs to determine the limits of the devices at this point. In the study by Hareide & Ostnes (2017*b*) eye-tracking technology was used in the same simulators, which appears to work reliably. This implies that the pupil labs devices work worse in difficult situations such as under low light conditions. Furthermore the software was limited in the analysis of the data. Therefore it was inevitable to go through the footage for any later statistics on the collected data.

5.1.3 Check actions for uniformity

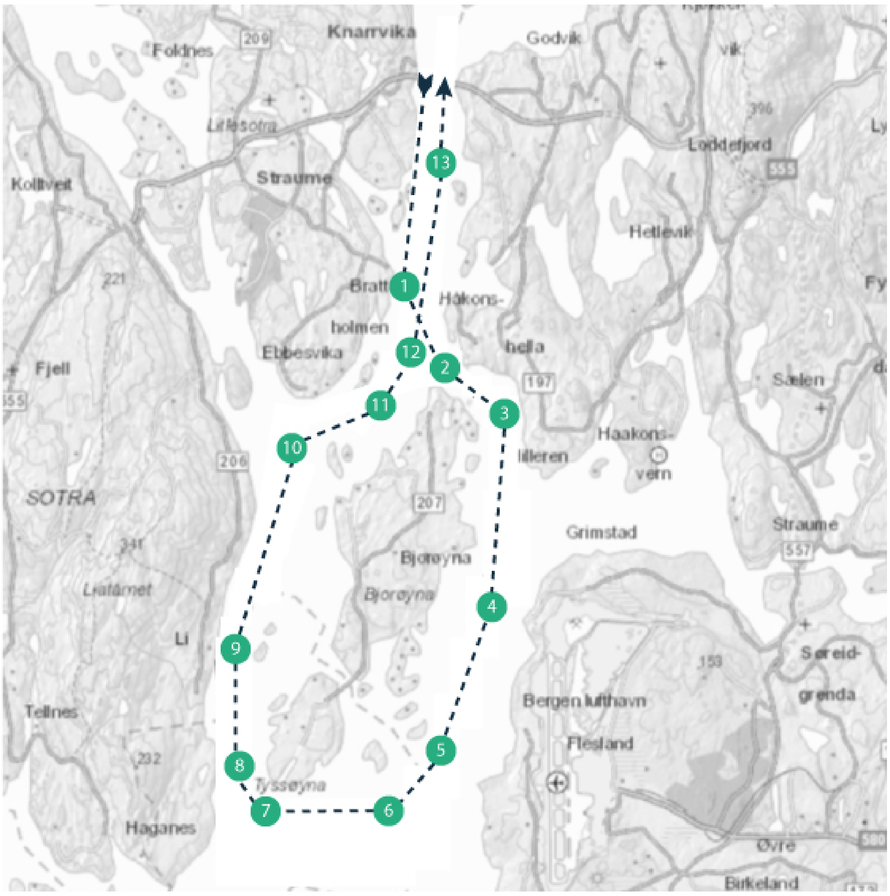


Figure 5: Map with listed course including the corresponding turning points (1-13)

Before trying to make any consumption on the visual output of the AOI data, the experiments should be a check on their accuracy, checking the times to make sure that the videos are comparable to each other. Therefore first have had a look at the ECDIS from the actual video footage from the Assistant (Figure 4).The Navigator and Assistant try to follow a predefined course on the map, which has predefined anchors or turning points. Following these points will make sure, that the vessel stays on course and stays in safe waters. By looking at the map from the ECDIS all anchor points could be spotted, which made an amount of 13 anchors. Carrying over the anchors to the existing map (Figure 2), it looks like Figure 5.

The 13 anchors in Figure 5 got defined before they started the simulation. Hence they encounter a ship situation (around anchor 12 in Figure 5) on the last segment before arriving, the last anchor (number 13) will vary from team to team and more turning points will come up, making it difficult to compare.

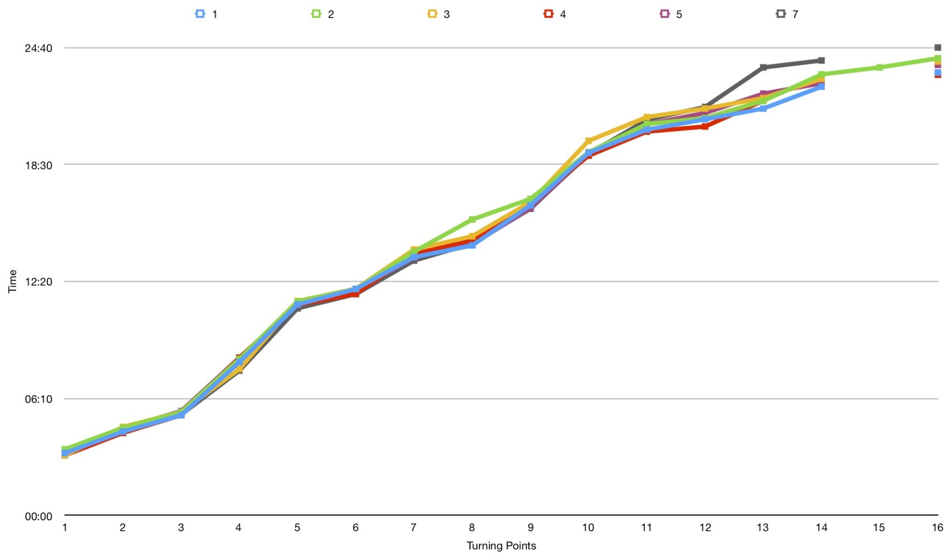
Therefore a table (Table 6) was created to compare and check when the different bridge teams reached the individual anchors. Time was noted down as a turn was initialized at one of the anchors. The initialization could be identified by the helmsman, who started steering the wheel and the indication line on the ECDIS which was changing the direction. Accept two times, participants' team 2 and 4, the anchors got reached by the vessels at very similar times, which means the data is good to use for a comparison between the participants in terms of time. As seen in Table 6, the green marked cells in the table represent the evasion maneuver mentioned earlier. Depending on the teams decided they had less or more turns used before coming back on course.

Also, the diagram in Figure 6, created from given table, presents the differences more visible as the later points are getting fuzzier. Interestingly the reaching times of the anchors are starting to change from point 10 where the teams approximately arrive at the part with a crossing ship. It seems like the standard procedure is done very precisely until the 10th point and changes as situations get unexpected and improvised. This might imply that the chance of same or similar patterns might decrease as soon as something unexpected interferes. This question will however not be covered in this thesis.

5.1.4 AOI basic considerations

After intensive video analysis, checking every second the gaze of one participant, corresponding tables with the earlier defined AOIs were created. The table included for every changing AOI a timestamp (start and end), the duration, an ID for the AOI, and the team-position. To compare the tables of the participants with each other they got merged into a single file to process further. During the process of video analysis additionally, tables of joint vision and non-verbal activities had been made (Appendix A.7).

A simple stacked bar chart (Figure 7) of the different AOIs on each participant reveals that looking at the data can clearly define a role just by visual inspection. By looking at the diagram one can recognize immediately the difference between Navigators and Assistant. The average time used by all teams for the simulation was around 25:12 minutes and a standard deviation of 00:20 minutes. This confirms accurate navigation within the teams, considering the length



Experiments / Turning points

N°	1	2	3	4	5	7
1	3:17	3:29	3:10	3:10	3:16	3:14
2	4:25	4:37	4:40	4:21	4:35	4:22
3	5:17	5:27	5:27	5:17	5:30	5:19
4	8:05	8:15	7:43	8:19	8:19	7:38
5	11:07	11:17	11:18	11:06	11:06	10:55
6	11:56	11:56	11:57	11:41	11:50	11:40
7	13:37	13:54	14:01	13:47	13:36	13:26
8	14:14	15:36	14:43	14:31	14:17	14:20
9	16:21	16:41	16:31	16:27	16:13	16:10
10	19:07	19:09	19:45	18:58	19:02	19:04
11	20:20	20:38	21:00	20:14	20:37	20:51
12	20:53	20:57	21:27	20:30	21:13	21:32
13	21:27	21:51	22:00	21:52	22:14	23:37
14	22:36	23:15	23:01		22:47	23:59
15		23:37				
16	23:21	24:06	23:56	23:14	23:45	24:40

Figure 6: 1. Table of Anchor points, shows reached times at the turning points for the different teams; 2. Graph of turning points: X-Axis: Turning points; Y-Axis: Time

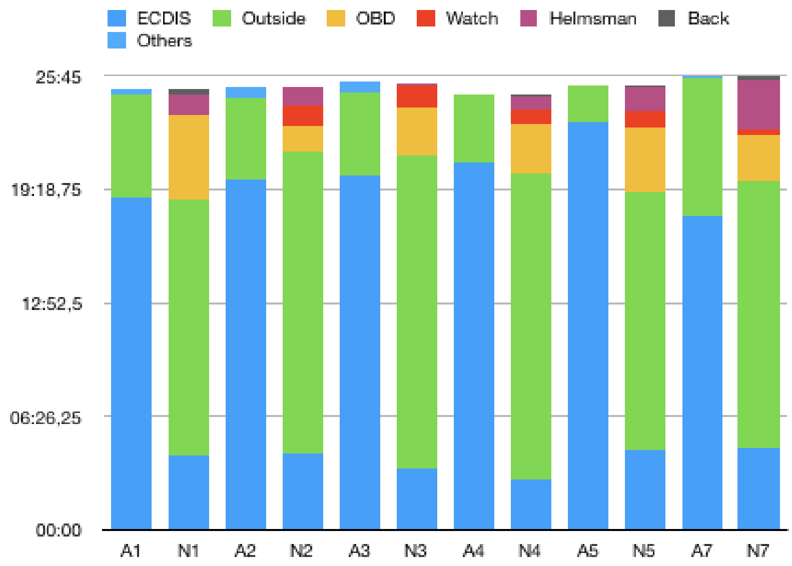


Figure 7: Graph of AOI Distribution: X-Axis: Assistant and Navigators; Y-Axis: Time spend on AOI

of the route and the various performed actions by the participants. Looking at the diagram, the Assistant spends the most time on the ECDIS, which is on average 80% (20:06 minutes) and on the outside, being 19% (04:48 minutes). The Navigator presents another defined deviation of the AOIs upon all Navigators, which sets its deviation apart from the Assistants. Most time the eye spends on the outside – around 64% and around 16% is spent on the ECDIS, which is almost the opposite deviation of the Assistants. However, the Navigators also spend 12% of the time on the OBD, 4% on the Watch, and 5% on the Helmsmen's instrument and the back-projection.

5.2 Results

Using the previously created table (Chapter 5.1.2) of AOIs over time data, let one construct a time-series diagram as a flattened Gantt-diagram. This way allows it to arrange and order all participants' AOIs-time-series-diagrams to one overview series-diagram. By laying them one below the other it supports comparing them to find similarities aka patterns or dependencies. To create such time series diagram the web-tool rawgraphs.io (RAWGraphs 2020) has been used. The data can be visualized in various ways, depending on the focus. The rendered diagrams can then be exported as an SVG-file to modify it later to the needs in a vector-based program.

1. AOI-Time-Diagram: Teams grouped

In the upper diagram of Figure 8 (or look closer in Appendix A.8), teams of Navigator and Assistant were placed under each other. As one can see, it looks very overwhelming at first sight. As it indicates from the earlier graph, the Assistant seems to have much more red stripes which indicate the long time he looked on the screen of the ECDIS. The Navigator on the other hand

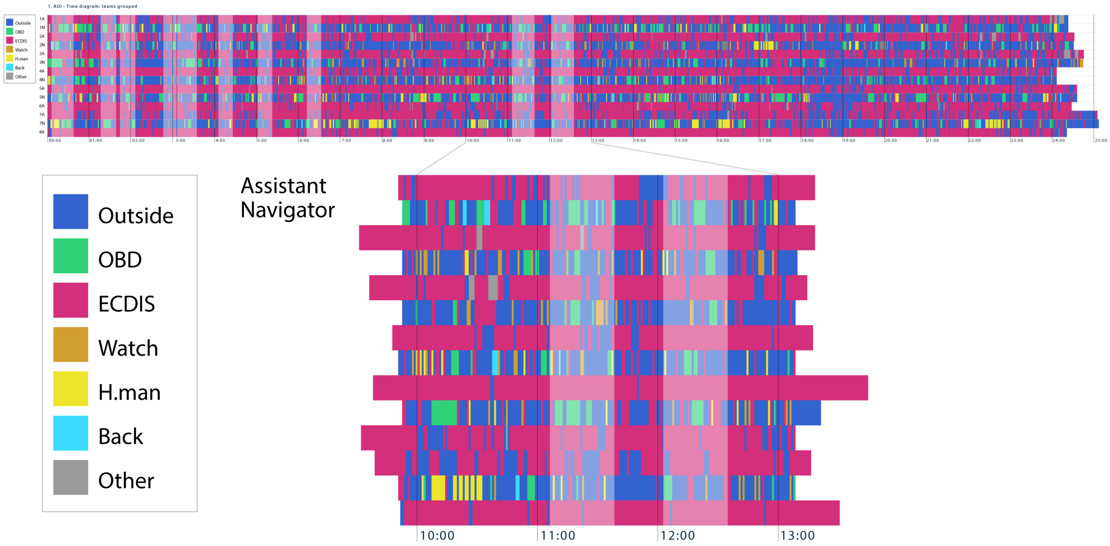


Figure 8: AOI-Time-Diagram: Teams grouped

shows mostly blue stripes, which represent the AOI of the outside. Focusing on the AOIs where the Navigator usually did not look at, for instance, the OBD (green stripes) or the watch (orange stripes), brings up similarities upon all the participants. This is demonstrated in Figure 8 and can be seen below at a closer look. This fragment in Figure 8 represents an excerpt from the AOI-Time-diagram between the minutes 10:00 – 13:00, showing the green lines (OBD-AOI) used at very similar time-frames in all Navigators AOI timelines. That indicates that there must be a Navigator action which is operated in very similar ways by all participants and is independent of verbal communication.

Moreover one can see that this action looking at the OBD (green lines) is later followed by checking the watch (orange lines) in most timelines. That can further mean that this action could be linked together, creating a pattern. By looking even closer, these two actions are appearing behind one another two times during the same time-frame of 10:00 – 13:00 minutes. This is a clear hint of a pattern – when looking into the real video footage and the route of the map, one will see that these lines appear in the turning phase. Moreover, this arrangement lets one compare the actions to the teammate's actions more easily to one another. As the green lines (OBD) appear in the Navigators timeline, you can spot the blue lines (outside AOI) on the Assistants timeline also appear at similar time-frames. This indicates that this pattern might need the action of both participants and are correlating.

2. AOI-Time Diagram: Position (Navigator/Assistant) grouped

By looking at the same data, but in a different sorted time-series arrangement (Figure 9 or Appendix A.9), the overall appearing looks different and is highlighting different areas. This ar-

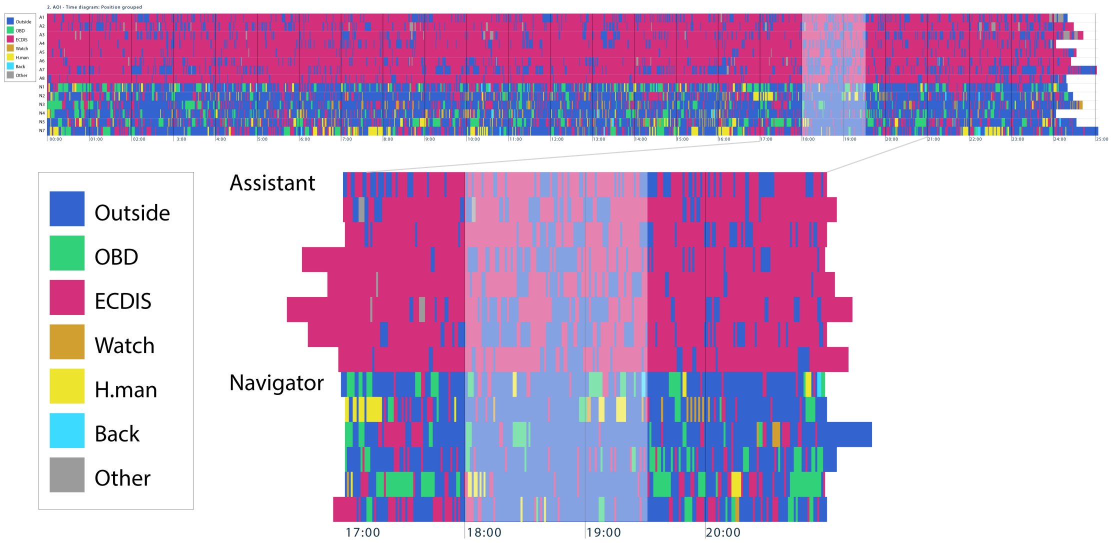


Figure 9: AOI-Time Diagram: Position grouped

rangement separates Assistants and Navigators, the first 8 entries are the Assistants and the last 6 entries are the Navigators. This AOI-Time Diagram might show more easily the problematic zones in which the team or a teammate had probably specific problems or difficulties.

Naval difficulties could be for instance represented by the yellow stripes (Helmsman-AOI), which seem to appear very irregular. Those can be found in the cumulative block of the Navigator-timelines. Even more obvious is the blue area (outside-AOI) between 17:00–19:00 minutes, indicating the need for information-seeking, which unknown target lies outside. These actions can be seen in the fragment of Figure 9 below the diagram. In this particular case, the video-footage reveals that it was the difficult section where the small ship suddenly appeared behind the shore and a close passing was necessary (see Chapter 4). But for now, irregularities are not the main focus and can be looked at as soon as standard patterns are found and defined. However, an approach to find those irregularities could be done by double-checking with the list of non-verbal activities (Appendix A.7) to find those dependencies. Caused by the overwhelming amount of information, it is not easy to spot any other patterns just by visual inspections.

That implies, without the help of algorithms or artificial intelligence, finding such patterns comes close to wild guessing. Hence this study tries to determine the fact that patterns exist, an exact listing of all patterns is at this point too far. Therefore, another way of proving that these patterns can be identified has to be done manually. A manual systematic approach has to be made which can interpret a pattern to be later identified in this timeline.

5.3 Conclusion

Since the visual inspection on these two diagrams is noticeable difficult, patterns or any kind of inferences is not easy to determine. As seen before, just little fractions as in Figure 8 and Figure 9 could indicate patterns but are no indication for a well-defined pattern. It does not give any clues about the participants' actions at that time, which in turn means that more background knowledge is needed to determine any patterns or to verify the predictions. Therefore, necessary to include knowledge about the actions which happened before and after each abnormality. Even though, notes were taken during the process in chapter 5, it turned out that these sporadically found actions are not easy to detect by just watching all footage separately, becoming way too chaotic and imprecise.

Thus, another iteration of the data analysis in a different systematic way is necessary, before working further on the time-series diagrams. A second independent iteration should also take care of the background knowledge of each action. At this point, a method has to be used, which does not include contextual verbal communication for the interpretation and focuses on the dual-eye-tracking. Communication in terms of verbal speech still needs to be considered, as it is a crucial part of the information patterns but has to be done without contextual knowledge. The actions itself have to be identified.

Furthermore, it is essential to include actions such as the act of controlling the watch, which cannot be seen from the video footage in the AOI observation itself. Using the watch is a necessary action by the Navigator, but they do not always look at the watch to use it, but it still needs to be included in the timeline as a new parameter. Consequently, crucial actions would get lost by just observing the AOI. Another layer of information could bring key-components to the considerations of patterns and their identification.

Additionally, unimportant or less relevant fixations can be ignored, as they produce a high noise into the overall timeline and suppress to highlight the key elements. But one has to have full awareness, hence more difficult patterns like information seeking between two or more AOIs could be generally overseen. On the other hand, long gaze resting on one AOI catches the attention visually and has to be compromised. Next, one could look manually for dense AOIs within the Navigators or Assistants to indicate different segments or phases of the tour.

6 Manual Analysis

6.1 Introduction

The last chapter 5 proved that identifying patterns by just analyzing a time-series diagram does not provide sufficient and efficient data. On the one hand, there is a high resolution of data, that is already too noisy, on the other hand too much excluded data to conclude patterns. This implies that more data has to be compared and considered at the same time. But hence it is impossible to try to understand the naval verbal communication without translation (see Chapter 6.3.5), the video footage of the eye-trackers remains as the main source to identify repeating behaviors. The eye-tracker footage itself is very rich in data, providing an egocentric video, which advantage it is to see what the participant is doing and at which areas information gets gathered. Thus revisiting the eye-tracking data is necessary, but the pattern has to be found in a profound and just visual way. Another disadvantage in this analysis is the deficit of naval understanding in general. It will worsen to find a connection between certain actions, which are followed by one another or repetitive. That gap of non-existing information has to be compromised by looking at other parameters in a new analysis as already found out in Chapter 5.

Therefore parameters the video footage from the eye-tracker provides, additional to the AOI will be:

- Conspicuous movements by the Navigator: going forward, next to the Assistant or Helmsman
- Non-verbal actions: pointing on the ECDIS/ outside
- Conspicuous sounds: Pushing the watch (beep), Lower/ rising the voice.
- Anchor points/ Turning points (Chapter 5.1.3).

6.2 Analysis Part 1

6.2.1 Method

In general, the next analyzing procedure of the video footage is a step-wise working through while systematically making notes for later evaluation. For this purpose, the determined AOIs from Chapter 5.1.1 will be used to keep the continuity and to keep track of where the participants look at (The AOIS are ECDIS, Outside, OBD, Watch, Helmsman, Back, and Others). With this in mind, a new hand-written time-series sequence will be created even though it could be probably done digitally. But for flexibility reasons, it will be created on paper to change things and making quick notes and decisions. Therefore a simple and flexible template will be used to structure the notes and information.

As seen in Figure 10 a timeline will be created for each of the participants. As mentioned before just 6 out of 8 experiments could be used for a strict comparison due to the two faulty

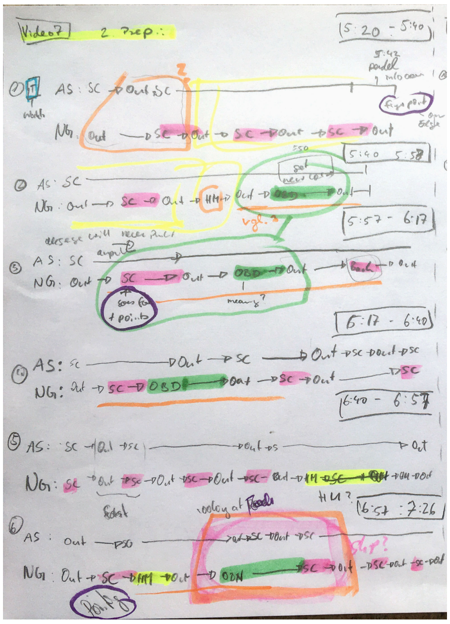


Figure 10: Example: manual time-series diagram, colored and marked with notes

recordings (see Chapter 5.1.2), which lead to an even smaller sample for this study. The timeline will have several layers for more presented information. The main or basic line will remain as the AOI, switching between the different areas. The data will be collected team-wise, Assistants and Navigators AOI will be noted at the same time above each other. The timeline for the Assistant will be on the upper part, the Navigators AOI will be below. Timelines will be broken down into around 30-second sequences, as the action or space itself allows it. Additionally smaller chunks of 30 seconds will make it also easier to focus on actions as it appears less overwhelming when hereafter analyzing it.

Each line gets a timestamp (start and end-time) to allow one to go back into the video to check the actions afterward. Below or above the timeline, another layer of information is used, to determine certain actions (mentioned in the beginning of Chapter 6) for either the Assistant or the Navigator. To speed up the process of taking notes acronyms were used for all kinds of actions and names. This process was finished for the moment after approximately 2 minutes were reached. These 2 minutes include around four successive timelines of 30 seconds, filling roughly one page. This one page would be ready to compare, but as it turned out, it was often easier to finish one whole phase (see Chapter 4.4) over several pages and go over to the analysis afterward.

When proceeding the video-footage, the timeline for the AOI was made by creating approximated horizontal arrows (see Figure 10), which are representing the length of the time spent on the AOI. As mentioned earlier, unimportant eye-movements are filtered manually out. For instance, when the Navigator looks from left to right, hovering over the monitors, often short saccades will appear. In most cases, these are mostly a longer saccade of the eye movement and would make the whole process unnecessarily complicated at this point. These saccades, or stopover of the eyes gaze, are ignored, even this would mean that some detail of information-seeking behavior could get lost.

Further, instead of focusing too much on the Outside AOI from the Navigator (spends around 64% of all time (compare Chapter 5.1.4), the less looked AOIs are from higher interest. This also includes the ECDIS (16%) since this is generally not the assignment of a Navigator and will sometimes be used for orientation, according to the cadets' interviews. Within this 16% might be a high chance to find patterns. All the noted parts of the Navigators AOIs, except the Outside AOI, got marked in specific and striking colors. This might help to focus on the parts where the AOIs will change to find visual patterns that repeat in certain areas during the navigation. Even though the focus should be on the Assistant and the Navigator, in this case, the Navigator will become higher prioritization due too the more obvious and active switching in the AOIs.

Moreover, the anchor points from chapter 5.1.3 will be used as sub-goals or as a frame in terms of markers on the timeline, which is a crucial point to identify patterns. By additionally framing these segments and putting them into the phases from the conference paper (Table 1) by Streilein et al. (2020) will support a better contextual understanding. For instance, the timeline shows the markers of the "Turning phase 1" and is between anchors 3 and 4, now an AOI order is "ECDIS->OBD->Outside" appears, this context will help to interpret the situation easier (see Figure 10).

6.2.2 Results

After completing the hand-written time-series from all available experiments for just one phase of the route, it was time to compare those with each other. At first, all pages from the different participants were placed in an organized pattern onto a wide surface. At the same time, just one or two 30-second timelines were looked at to compare them with each other. This helped to organize and get a good overview of all experiments at a time. At this point, it helped to have the additional layers of information (beginning of Chapter 6), instantly one knows were actions happened e.g. before and after a turning point. It also helped to have certain actions in mind such as movements of the Navigator to allocate those with the noted AOIs.

Sometimes similar segments upon the experiments just popped up straight away, others needed to be interpreted distinctly. Since the moment of the actions varies from team to team, it was sometimes necessary to jump back and forth to see if a similar segment can be found here. When similar segments were recognized, they were carefully marked with a distinct color in all available timelines (Figure 11).

When necessary, site-notes were still made to manifest any kind of thoughts and conclude any

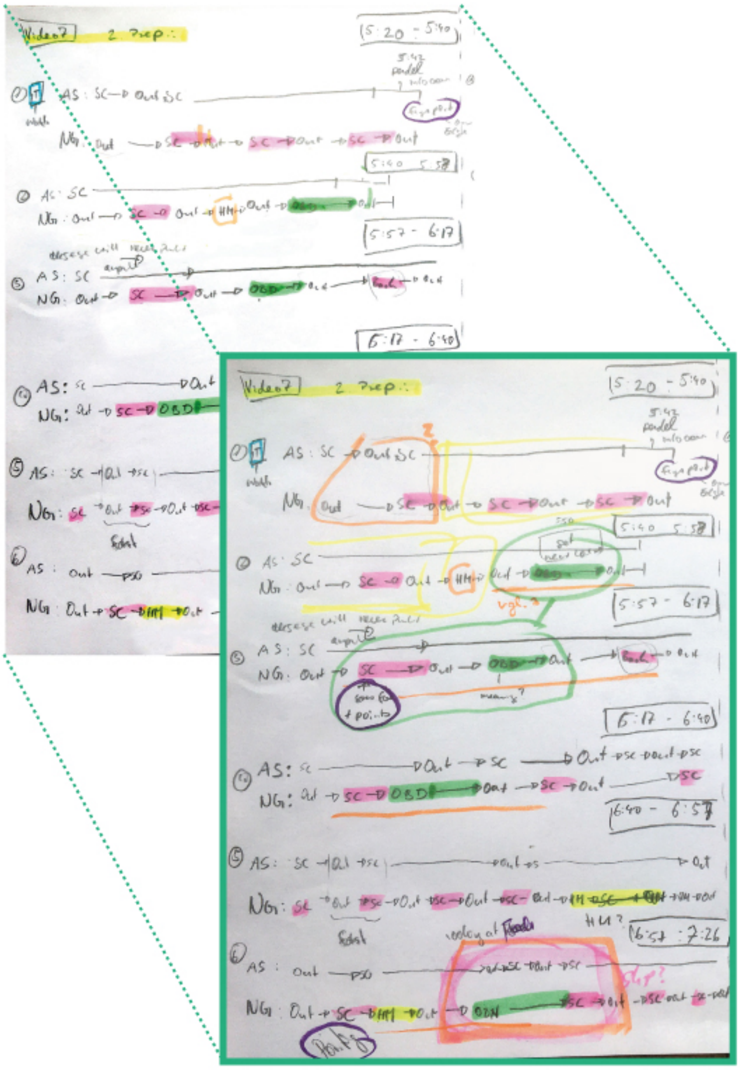


Figure 11: Manual Analysis Notes) Before: transcription; After: Pattern marked

coherence. Even though some identified segments were not 100% identically, they were marked with the same color for that moment. This helped to narrow the whole impression down even further, to the extent of seeing all the same core AOIs at this time. These colored segments formed finally a base for naval communication patterns. One page of an experiment often came up with those matching segments (Figure 12), which will be later used for creating a specific pattern.

Figure 12: Manual time-series: One page (ca. 2 min.) marks and notes of similar patterns upon the experiments 2,3,4,7

Sometimes it was helpful to go back into the video to review if the actions are comparable. To check what participants said at that time, even with language barriers, helped to identify market segments with the same color for the same problem. One can say that this extensive manual evaluation of the video footage can lead to patterns based on visual inspections, qualitatively describing the data. Further, it supports the prior defined phases from the conference paper (Table 1) by Streilein et al. (2020), hence similarly segments are identified within those phases.

6.2.3 Conclusion

The manual analysis is much more flexible and allows one to interpret the situation individually. The reduction of short-time AOIs and length of time is a crucial point, allowing one to understand patterns without understanding the exact verbal communication. A better understanding is also supported by shortening the length into capable sizes. However, this method is not very efficient in terms of time since the video footage has to be watched and evaluated several times. This method might work for short passages, but longer footage is not recommended. In this study, only the first 12 minutes were manually analyzed for the 6 experiments to compare. This is almost half of the footage and ended in the 2. Turing phase and made already 48 pages of hand-written time-series diagrams, which had to be compared afterward. Those 48 pages resulted in 8 pages (à ca. 2 min,) for each experiment.

It shows that it is possible to find repeating segments in small samples as an outsider, but it also implies that it might be important in further research to cooperate with people from the same field more closely to work more efficiently. Learning from the Navigator and the Assistant in how they work will help analyze the process and tasks while evaluating the video footage of the route. Working more closely would help to simply localize phases and tasks which would make it much easier to detect and rate those patterns. In this study, the knowledge about procedure and execution was build in an elaborate and explorative way.

Furthermore, the small sample of 6 experiments already reveals a huge variation in their behavior. One could imply that the base is too vague to come up with a general pattern caused by a lack of references. But more experiments would also take more time to compare and might make it even more difficult. One example of the variety in the sample is experiment 2, which showed always different AOIs than the other groups. That would imply that there might be a difference in training skills, affecting the way participants absolve the navigation.

Besides newly identified patterns, there was also an observation made about frequently happened actions. In general, when the assistant looks outside, this might come from different origins. The Assistant is normally used to observe the ECDIS but swerves from it as soon he sees something suspicious or dangerous like crossing ships or close coasts coming close. This effect can be seen perfectly in the time-series diagram from Chapter 8, where the color indicates irregularities. But except for this fact, it seems to randomly and too imprecise to generalize it since the sample size is also very small. There are another two situations where the Assistants look outside. The first situation is when the Navigator orders it, while he cooperates with the Helmsman. As from the interview taken, it is always necessary that one team member on the bridge keeps looking outside. Since this just happened once it cannot be an argument as a pattern. At last, the Assistant looks mostly outside while the Navigator uses the OBD. During the analysis, this behavior was noted as part of a pattern.

6.3 Anaysis Part 2

6.3.1 Method

After analyzing the eye-tracking footage manually it can be now converted into a digital version. This digital version can be used to compare it with the audio stream or other additional data-streams. Since the manual analysis only provides 12 minutes of analyzed data, the result will not cover the entire simulation, excluding the difficult parts at the end of the route. Therefore the evaluation can only deal with the constraint insight. The earlier found segments can be sorted into the first few phases of the experiment to create general patterns for this case study in a naval vessel simulator. All defined pattern will be assigned to the described sequences of the conference paper. Hence it is a case-study one can assume that the situations will change from case to case. Therefore not all determined patterns might be transferable to a general set of naval patterns. That means that noticeable and repeating patterns, in this case, do necessarily correspond with other situations or cases.

Those following patterns occurred upon the teams showing team-wise repetitions over time, that is why the same patterns get presented more than once. In the results section (Chapter 6.3.3) the patterns which are frequently showing up over time (just the analyzed 12 minutes of the experiment) will be presented.

Definition of pattern in this study:
A repetition of sequences, consisting of switching and predefined AOIs, upon several teams. In the best possible way, verbal communication aligns with the AOI. The patterns however will not be a real accurate representation in terms of time and can be only seen as a close approach to describe the actions. The length of an AOI time-span is approximated and not calculated, as it could have been done by using averages. This inaccuracy is due to the manual analysis approach which is not accurate and imprecise in terms of visualizing periods.

6.3.2 Results

For the digitalization of the segments into patterns, a vector-based application is used to illustrate the data (Appendix A.10). Additionally, each pattern will be described by the provided AOIs and by observation.

Initialize:
1) Getting on course - using OBD: It is noticeable that all teams have the same procedure at the beginning of the simulation. As implied from the actions they set the course. Therefore the Assistant looks on the ECIDS to provide coordinates while the Navigator changes his AOI form the Outside to the OBD, starting to exchange the coordinates. It happens that the Navigator also looks outside while using the OBD. At the same time, it is also noticeable that Assistants tend to look at the same spot Outside where the OBD is directed to. Afterward, both return to the basic position (Assistant watches ECDIS/ Navigator watches Outside). This procedure takes about 20 seconds of the beginning.

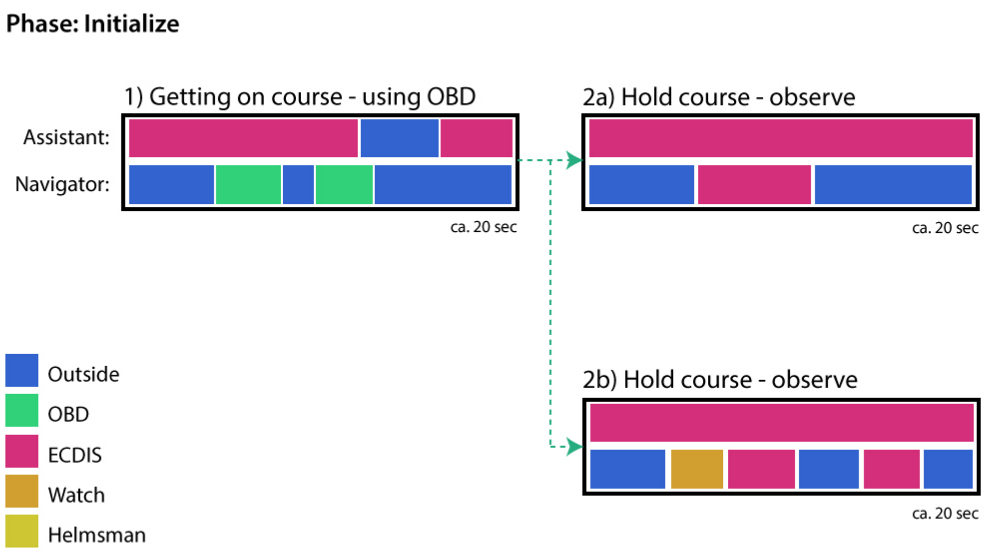


Figure 13: Phase: Initialze - 2 patterns

2)Hold course - observe: Followed by the first pattern a straight course follows down till the next turning point. In this passage it is very calm and nothing serious to expect. Therefore both team-mates have to observe the environment before the situation changes to the preparing phase. The Assistant uses the ECDIS to observe and plan, while the Navigator observes the Outside. It is very unlikely that the Assistant looks out at this point. The Navigator however might check the ECDIS to orient himself. One group used the watch to make measurements, showing some variation at this point.

1. **Prepare:**

3)Checking and compare course – variation : The preparing part starts by setting the course towards the next turning point on the ECDIS. In this case, there is a huge variation in how the participants used it. As seen in Figure 14, there is a larger group of teams using the OBD and 2 teams, which are using other ways in the beginning. This 30-second part demonstrates that even this small sample already contains a huge amount of variety (will be left out in further progress). In the larger groups, the Navigator is using the OBD several times (indicated by the green blocks), while the Assistant looks on the ECDIS most of the time. There is a variation in how many times the Navigator looks or uses the OBD. In two cases the OBD is never used during the first 30 seconds of the beginning of the Preparing Phase. In one case the Assistant looks way more often outside compared to all the other experiments. In the other case, the Navigator is

Figure 14: Phase: 1.Preparation – 3 Pattern + Variation

looking between the Outside, Watch, and the ECDIS, having a different behavior at this time. In total, this passage does not show a repeating pattern upon the teams.

4)Checking course: longer version: This pattern occurred in almost all of the experiments, except one. Right after both looked outside, they check the ECDIS. After the Navigator observed the Outside for a bit longer, he turns toward the OBD. While the Navigator using the OBD, the Assistant looks at the same point Outside. After the usage of the OBD, the Navigator turns away and also looks shortly Outside, before both the Navigator and the Assistant face towards the ECDIS to check it. In only one case, the Navigator swaps looking between the Outside and the ECDIS back and forth, plus checking the watch once in-between.

5)Identify problem: Pointing ECDIS - Use OBD: This pattern got found in four of the experiment teams, describing a problematic situation. The situation gets initialized by the Navigator, who turns away from the Outside and points on the ECDIS. One can imply that the Navigator and the Assistant discuss the upcoming situation since there is an upcoming turn further away. After looking at the ECDIS, both are checking the Outside, followed by a short check on the OBD. The Navigator is double-checking on the ECDIS before turning back to observe the Outside.

1. Turn:

6) Correct course var.01: The turning phase, in with that the first turning point, comes with two patterns that shortly follow after each other (see Figure 15). This combination was found in most experiments during the analysis. Slightly before the turning-point is reached, the team uses the OBD. One can imply that the OBD gets checked, to get to know if the vessel reaches the turning point correctly, otherwise, they might want to change the course coordinates. While

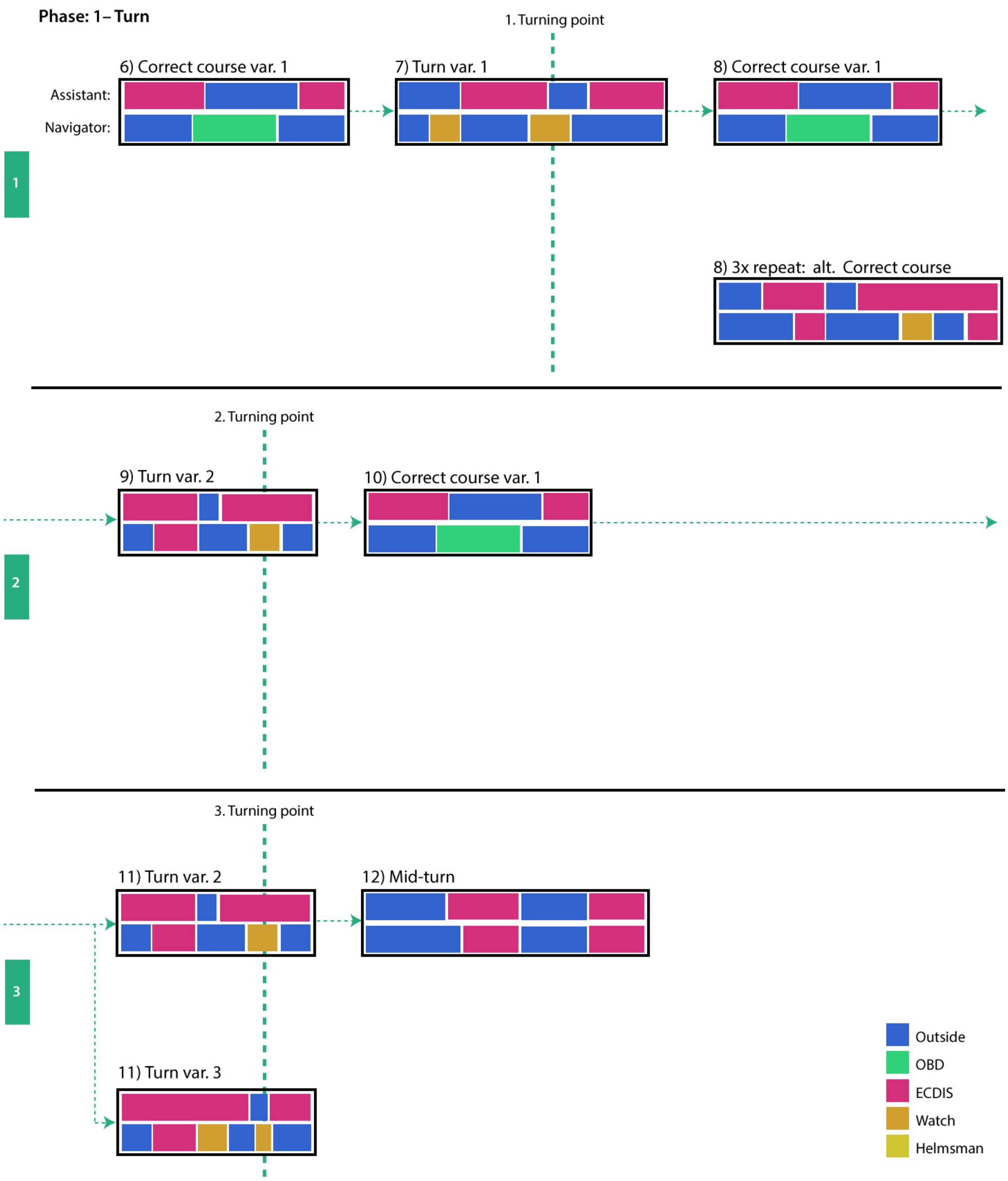


Figure 15: Phase: 1. Turn – 7 Patterns

the Navigator looks into the OBD, the Assistant looks outside at the same spot as the Navigator looks. When the Navigator finished his action both return to their initial observation. The time to reach the turning-point varies from team to team.

7) Turn var.01: This turn is the following action by the earlier correction-pattern. Before the turning point is reached (symbolized by the green dotted line), some quick changes of the AOIs are happening. Shortly after both teammates looked Outside, the Navigator checks his Watch and the Assistant returns his attention to the ECDIS. Now the Navigator looks Outside and is waiting for the moment the turning point is reached. Exactly when the vessel reaches the point, the Navigator uses the watch again by pushing it. Both members looking Outside, the Assistant however looks quickly back to the ECDIS. During this phase, a lot of verbal communication is used, which will be explained later (Chapter 6.3.5).

8) Correct course var.1: Between the Turning-points, many AOI changes happened, but one pattern has been found in-between. The same pattern as Correct course var. 1 appeared often, showing that they used the OBD again while they are heading towards another Turning-point. As before, one can imply that they make sure to be on track. Except for one experiment (2), it shows a frequently happening sequence of the changing AOIs. The navigator uses the Watch to hold the course, orientating on the Outside. During the correction, verbal communication seems initialed by the assistant who is providing new information.

9) Turn var. 02: This turning pattern is slightly different than the Turn var. 01. Before all teams reach the turning point, both respective team members are looking at the ECDIS. Right after both are looking Outside, the Assistant provides new information. The Assistant looks back onto the ECDIS, shortly followed by the Navigator, who is using the Watch and initiate the turn (the Helmsman is steering). The increasing communication during the turn is noticeable.

10) Correct course var. 1: This is another "Correct course var. 1" during the same turning phase. Just as before, the Navigator uses the OBD, while the Assistant looks at the same spot Outside.

11) Turn var. 02 (+Turn var. 01): This turn repeats the same pattern as the one before at the last turning-point. Another variation of the turn appears which is similar to the Turn var. 01, except the fact that the Navigator looked at the ECDIS before using the Watch twice.

12) Mid-turn: While the vessel turns, the Navigator and the Assistant are observing the ECDIS and the Outside alternately together. Almost at the same time, they both look Outside as soon as the Helmsman steers the wheel. Shortly after, they both check the ECDIS before they look Outside again. For the second time, both look back to the ECDIS shortly before the turning-action is done, which is ending the Tuning-phase and bringing the vessel back on course.

2. Prepare:

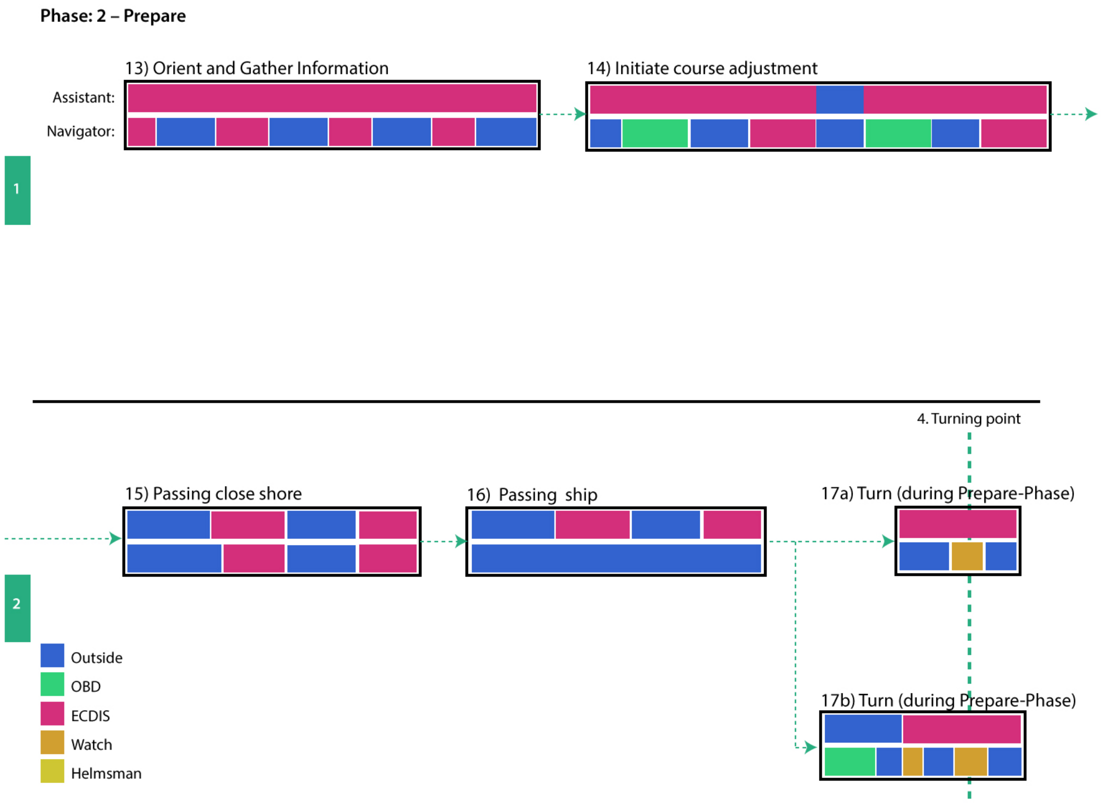


Figure 16: Phase: 2. Preperation – 5 Patterns

13) Orient and Gather Information: After the Turning-phase, it gets way calmer in terms of communication. Both team members focus on their work. The Assistant works and observes the ECDIS. In the meanwhile, the Navigator gathers Information around the vessel and its environment and checking the ECDIS alternately. The AOI of the Navigator is switching several times between Outside and ECDIS.

14) Initiate course adjustment: During the 2. Preparing-phase one turning point appears halfway where the Navigator has to adjust the course a little. Therefore the teams seem to check whether the vessel is heading towards the turning point. Before that, a slightly different pattern comes up. In the first pattern, the Navigator uses the OBD twice, while the other pattern is a combination of using the Watch and the OBD. In the second half of the pattern, the Navigator uses the OBD in both patterns. But first, he looks with the Assistant on the ECDIS before both switches the AOI to the Outside and then towards the OBD.

15) Passing close shore: The team shows similar behavior in terms of AOI when passing a close shore. Also, here AOIs are switching simultaneously between Outside and ECDIS by the

Assistant and the Navigator.

16) Passing ship: Other than the passing shore situation before the Navigator does not observe the ECDIS while a ship is passing. However, the Assistant alternately switches between the Outside (ship) and the ECDIS (ship).

17) Turn (during Prepare-Phase): The turning-point during the Preparing-Phase is noticeable less active in terms of the AOI movement and verbal communication. In most cases the Assistants AOI lays on the ECDIS while the Navigator uses the Watch once at the point is reached. The divergent version shows the Navigator checking the OBD before he reaches the Turning point. While he is using the OBD, the Assistant looks Outside.

6.3.3 Conclusion

After looking through the repetition of the team-based patterns, managing the manual time-series, one can now identify patterns that are also repeating within the analyzed time. It is noticeable that there is a repeating pattern during every turn. Each time the vessel comes across a turning point, the AOI sequences show a very similar pattern with only slight differences. Figure 17 demonstrates all the variations of tuning within the 1. Turning-Phase. There are just slight differences, the time the Assistant looks outside sometimes varies, as the AOI amount on the ECDIS varies on behalf of the Navigator. Those three patterns also show a difference in usage of the Watch. One can assume that these patterns are similar due to the perfect trained participants and the naval standardization.

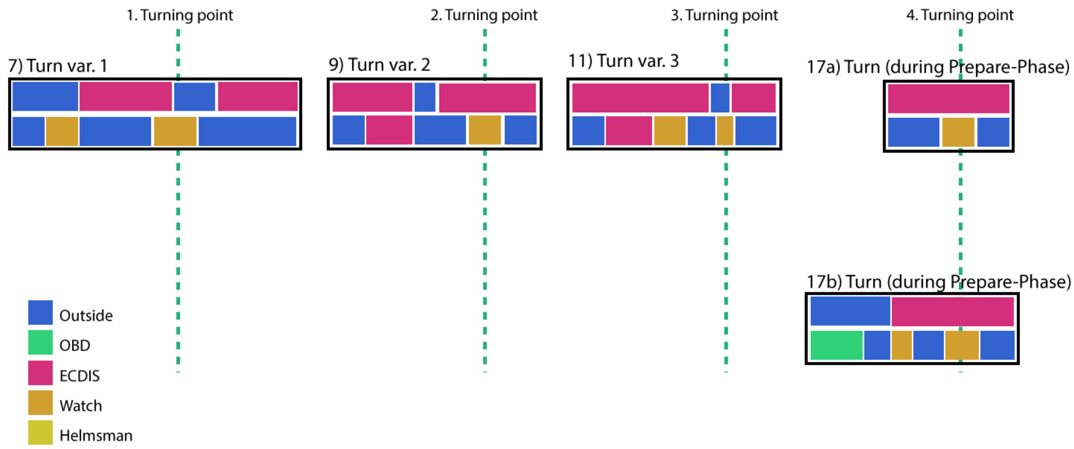


Figure 17: Pattern 1: Turning Pattern (Turning Phase (3), Prepare-Phase (1))

Another example of multiple repetitions was the usage of the OBD in the passages in-between the 1. Turning phase (see Figure 18). Before the vessel approached a new Turning-point, the Navigator used the OBD to check coordinates with the Assistant. While doing this, the Assistant normally looked outside.

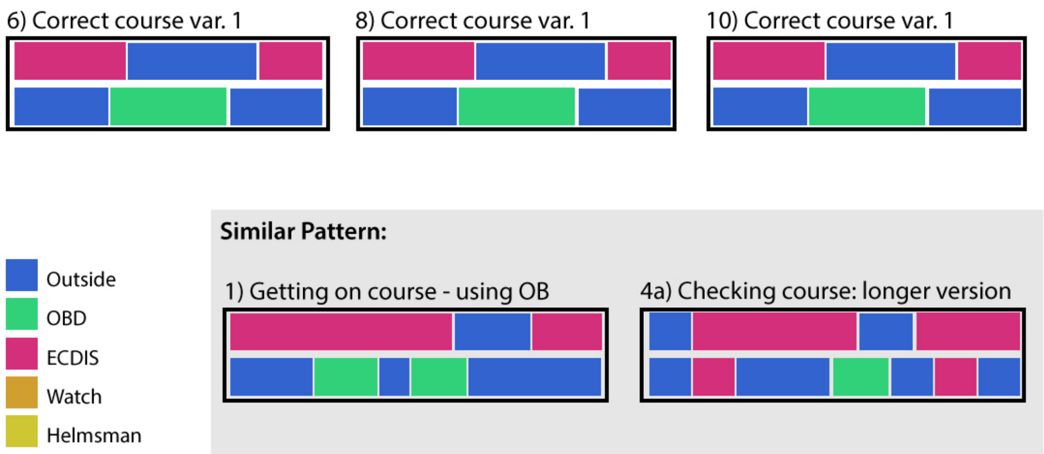


Figure 18: Pattern 2: Use OBD

The last repeating patterns occurred during more tense situations, which catches both cadet's attention (see Figure 19). For example, when the vessel passes by a very close shore or is in the middle of the turn, the Navigator and the Assistant are simultaneous looking at these areas. Hereby they are both switching the AOI between Outside and ECDIS together. This pattern seems trivial, but was found upon all teams. Other than the first Turn-pattern or second OBD-Pattern, this pattern does not seem to apply to naval standardization, it might be unconscious behavior.

For the rest of the found pattern, overall summarizing is not yet possible, since the analyzed data does not provide enough data to make more assumptions. However, the data has still a high potential. One can assume that the next following phases (Turn and Prepare) of the second half of the experiment are expected to show similar patterns. Interestingly both team-members often look at the same spot (joint vision) in these found patterns. It might imply that joint vision is a crucial component in terms of patterns or situations, possibly indicating more crucial operations.

The content of the video-footage probably contains even more pattern which could not be found yet. This analysis is very individual, hence there is a lack of language and naval knowledge, many

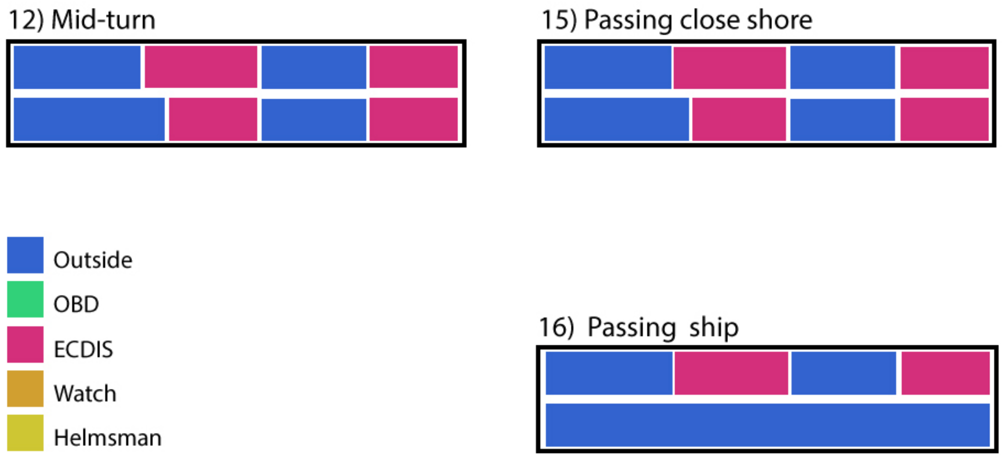


Figure 19: Pattern 3: Tense situation

actions could not be interpreted. Background knowledge is missing to link actions and to have a general sense of the situation. Therefore, one can assume that these found patterns are detected due to the professional and consequent training of the cadets. Further, the high standards of naval operations and a closed-loop communication contributes to a similar sequence of actions. However, it is impressive to see how these factors, such as the taught standardization, are not just affecting the operation itself, it further affects the eye-movement, which is demonstrated by the same sequences of AOI in a pattern.

6.3.4 Patterns compared to AOI-time-series diagram

The overall patterns from this case study were introduced in section 6.3.2 and will be now traced back to match with the time-series diagram from Chapter 5.2 (also check Figure 8). If these patterns, created by the manual analyses, can be found in the time-series diagram it implies that patterns can successfully be found by manual observation and analysis.

Due to the small saccades, the diagram form the AOI-time-series seems slightly more inconsequent and complex, since the manual analysis was more generous about saccades. However, when comparing the diagrams excerpts to the previously created pattern, one can definitely see similarities. Figure 20 displays a few patterns from section 6.3.2 (see pattern: 1,4,5,7,8) in comparison with the corresponding excerpts from AOI-time-series diagram.

This observation reveals that there is a strong connection between the Assistants' eye-movements and the Navigators' eye-movements. They formed a duet and for future analysis, it is important to treat the movements of both as one activity. Further, it explains how important it can be to use eye-tracking on more than one person in team environments in future studies to understand dependencies.

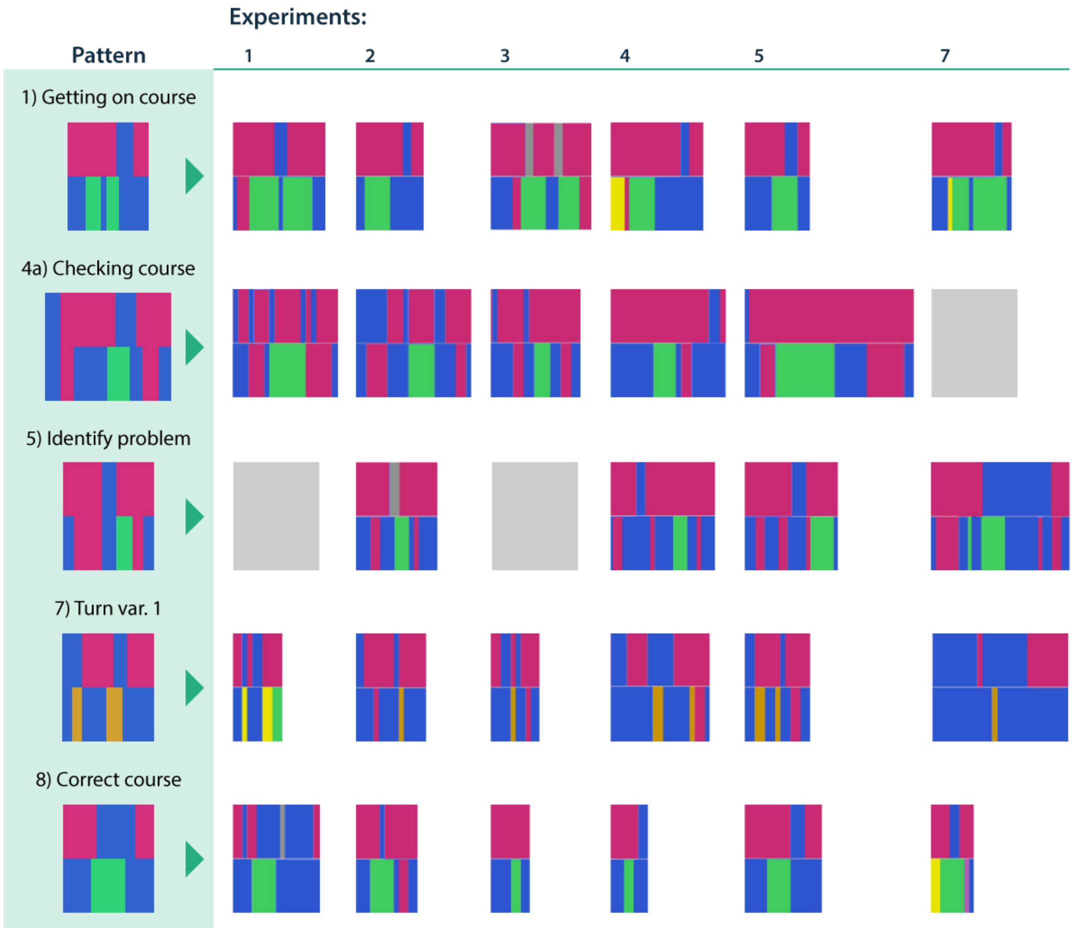


Figure 20: Manual Pattern identified in the experiments AOI-time series (snippets)

6.3.5 Patterns compared to audio

Hence patterns can be momentarily detected visually, by AOI comparison, verbal communication adds another layer of information. With audio, it might be possible to indicate new patterns or patterns which follow a similar pattern as the AOI. Further, it is to identify if these AOI patterns connect to the audio. Therefore, plain audio-wave will be used first and applied to one of the already found patterns. In a second step, the audio data will be converted into a table-format, having the communication reduced to time-stamps. Each time a team member communicates an entry will be made in the table. This table will be further exported as a diagram, which can be added to the AOI time-series diagram to compare those (Appendix A.11). Besides that, it turned out that modern artificial intelligence (A.I.) cannot transcribe the audio to text since those A.I. are not qualified to understand basic naval commands and naval communication. Therefore, more extensive speech analysis needs to be done by native speakers.

In Figure 21, one can see the third pattern from Chapter 6.3.2, where the Assistant provides coordinates, then the Navigator uses the OBD and subsequently confirms them. Presented in Figure 21 are the first four experiments (others had sound issues), overlaid with the corresponding sound-wave. In the first row, the Figure shows that the sound-wave is not optimally fitted into the created pattern, but still one can see that certain AOIs appear together with speech. The second row shows the raw sound-wave. As in experiment 1,3, and 4 seen, the Assistant only talks when he looks onto the ECDIS (pink color). The Navigator on the other hand talks mostly around the time when he is using the OBD, which is logical since he repeats the provided coordinates. The only exception is experiment 2, where the Assistant does not talk at all, and coordinating is done by the Navigator. In Experiment 4 the Navigator immediately talks again after the Assistant replies, the audio behaves otherwise just as experiments 1 and 2. To demonstrate the changes in communication between Navigator and Assistant, the third row in Figure 21 shows the communication highlighted in green. Here one can see the differences better upon the experiments in terms of verbal communication. This example shows, that even if the AOI pattern is almost the same, the verbal communication itself can vary slightly (experiment 2). However, one can also see that there is a good chance of similar verbal communication, following the pattern of the AOI.

Next, it could be considered to minimize the audio-wave to abstract blocks, as it is similar to Figure 21, row three. Using Audacity (Mazzoni 2000) and its Plug-In Noise-Gate it is possible to create a threshold and delete background noise in the audio recording. Afterward, the audio tracks can be analyzed automatically by audacity, to create a file with time-stamps for actively spoken parts. This file can be loaded into RAWGraphs (2020). After exporting another Gantt-diagram based on verbal communication, it can be merged with the AOI-time-series diagram. The result can be seen in Figure 22, using a given pattern as an example. The black lines above and under the AOI time-series fragment shows the audio amplitudes from the audacity table. But as one can see, the result is not perfect and the lines do not perfectly align with the audio-wave. However, such addition to the AOI-time-series would help to characterize the patterns more simply.

The audio data provides an extra layer of information to the given pattern, helping to understand the situation better. To understand verbal communication is not yet necessary. More interestingly, this short example presents an audio pattern. One can imply that there is a high chance of coherence in verbal communication and AOI sequences. Further studies could investigate the audio patterns and correlation to the AOI. Most likely patterns will be found due to the standardization

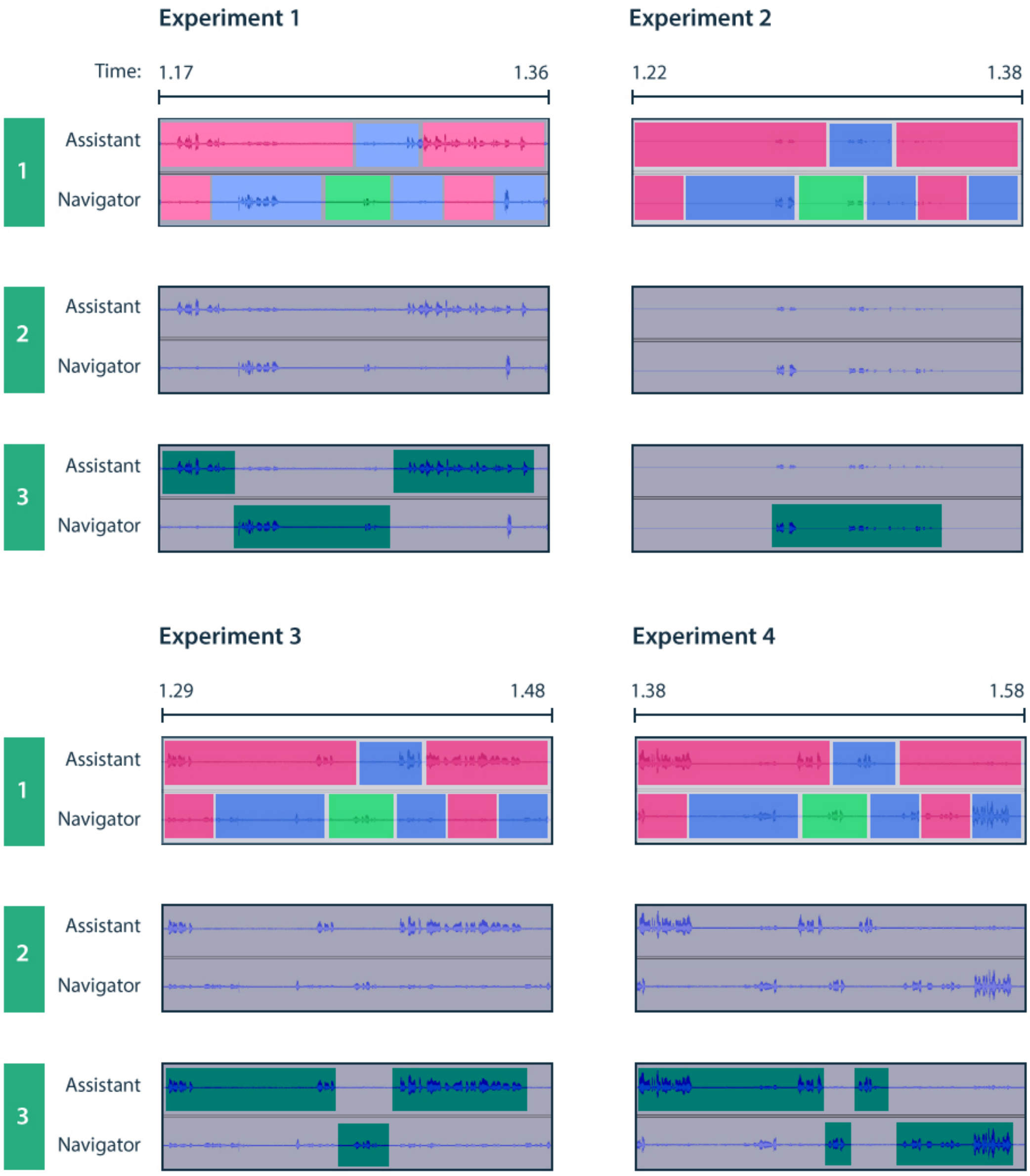


Figure 21: Audio overlay - identify similarities

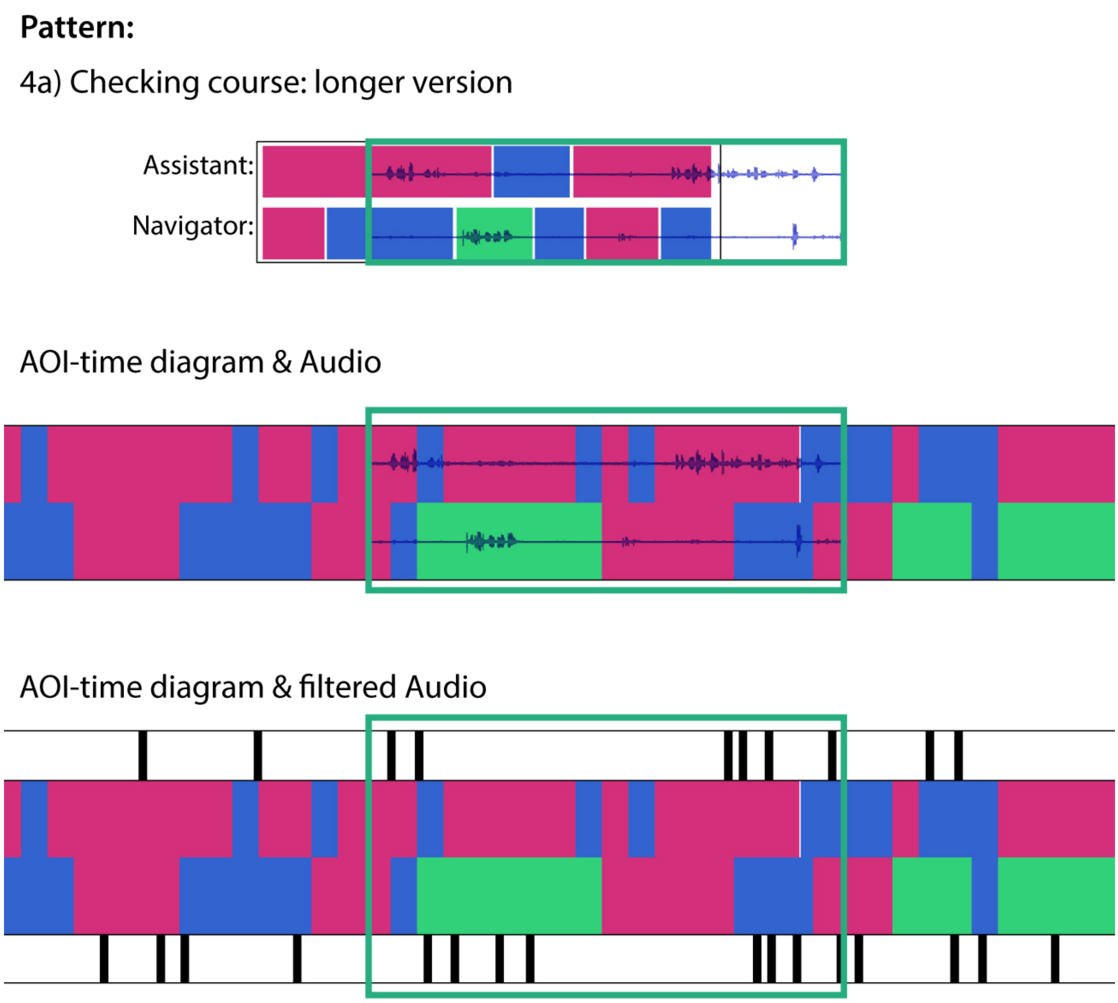


Figure 22: Abstract Audio overlay vs. Audio-wave

in naval communication. In general, small talk is nonexistent and communication is a tool to provide information and complete operations. Future investigations could add other factors to the given patterns and define those in several ways, depending on the needs. For instance, the inclusion of workload would be beneficial, to investigate normal and critical patterns in terms of navigational skills. If cadets showing critical patterns with a high workload, such knowledge would help to provide a profound understanding of how to improve navigational skills in the long term. Other factors to investigate could be the team's physical movements and motion patterns, which might indicate different problems.

6.3.6 Conclusions on the questionnaire

Finally, the results from the questionnaire can be used to compare the earlier conclusions. At this point, Question 2 and Question 3 (see appendix A.4) will help to make assumptions on the self-appraisal of the cadets. The colored maps were scanned and stacked over each other for the Assistant and the Navigator, which results in Figure 23 and Figure 25. In the next step, the route from the stacked maps was separated into 50 segments, in which color-value was read and transferred into a table (Appendix A.14 also Figure 24). In the following, both questions will be discussed.

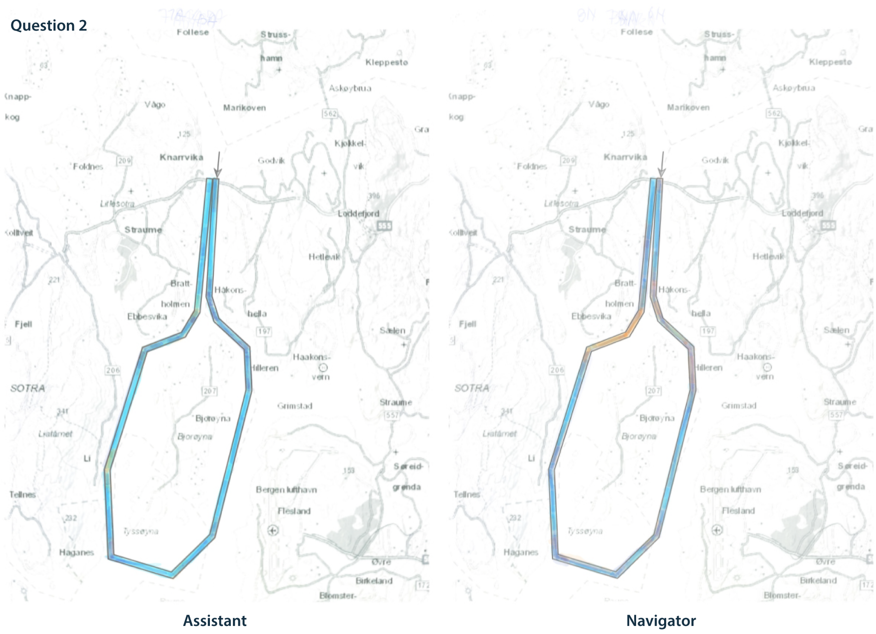
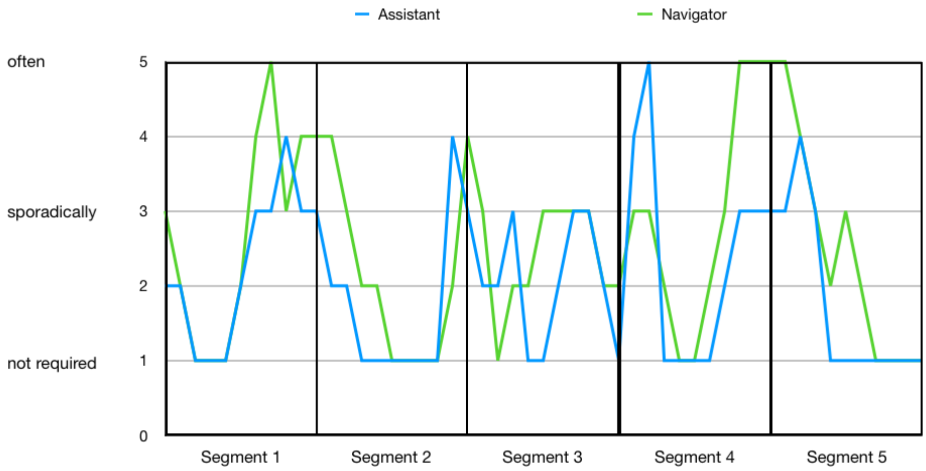


Figure 23: Colored Map - Question 2

Question 2 - Conclusion

How frequently you require information from your team-mate?

Here are the overlaid maps with all the participants' answers stacked over each other (the individual maps can be seen in the Appendix A.13). The answers on the colored map seem to be very different, but stacking them over each other reveals that in general information is needed around in the turning phases. Especially the map from the Navigator shows a deeper coloration, which infers that the Navigator in general needs more information in these areas than the Assistant. Compared these to the pattern from the time-series (See Figure 14; 15;16), one can infer that these are the main areas where the Navigator uses the OBD to check the course (see pattern 2 in Figure 18). In these parts, as seen in (Chapter 6.3.5), the Navigator receives a lot of information from the Assistant.



Average Q2

	Assistant	Navigator
Segment 1	2,27	2,73
Segment 2	1,70	2,10
Segment 3	2,00	2,40
Segment 4	2,40	3,00
Segment 5	1,70	2,30
	2,01	**2,51**

Figure 24: Segments: Average - Question 2

The colors from the questionnaires got picked and were translated into numbers of 1-5 (see Figure 24) and the averages were calculated. As one can see the segments (from Figure 2 with more turns (1;3;4) are having a higher average. In general, the Navigator has a higher average of 2,51. The sample is quite small and the answers are partly varying a lot, but comparing these conclusions with the recorded audio would be an interesting analysis in the future. That could help to verify if communication is getting more on behalf of the Assistant in terms of verbal communication. This could further be compared with the joint vision data to see if verbal communication has an impact on a joint vision.

Question 3 - Conclusion

What is your primary source of information during the navigational course?

To answer question 3, the participants had the choose between these three options: environment(blue); instrumentation(red), and a teammate (orange). The results were stacked together as done before to gain an average result of all the participants (see Figure 25). Unfortunately one cannot see a good separation of the colors, which are blending into each other. But the route of the Navigators differs extremely from the Assistant. The Assistants route shows only red and blue, whereas the Navigators route shows all colors spread along the route.

Figure 25: Colored Map - Question 3

To gain a clearer image of the maps, these results were also translated into a table (Appendix A.14). Therefore the route was divided again into 50 segments, which colors determined the new average color. With this data, the picked colors could get applied on the route (Figure 26), which now clearly present the answers of the participants. These maps reveal that the Navigator, as in the AOI-time diagram (Figure 8), collecting data from multiple sources to navigate. The orange segments (get information from team-mate) in the Navigators map are exactly located in the Turning points, which infers that they are dependent on the Assistant at this point. This fact is also covered by Question 2, which showed that the Navigator needs more information as usual at these points.

However, the Assistant shows only the colors blue (outside) and red (ECDIS), which is identical to the used AOIs and can be proved by the AOI-Time diagram (Figure 8). Between the turning points, the map shows blue parts, which means that the Assistant looks outside. One can infer that he is looking outside to gather information and to prepare new coordinates for the Navigator. In this part, it can also be observing of intense situations, such as crossing ships and close shores, which can be supported by the found pattern 3. (Figure 19, the observing pattern), which also occurs at similar parts on the route.

This map has not been compared to the AOI-Time diagram yet (Figure 8), to see if the cadets' self-appraisal shows similarities and correlations. Unfortunately, the rest of the questions (4 and 5) were not meaningful enough to be presented at this point.

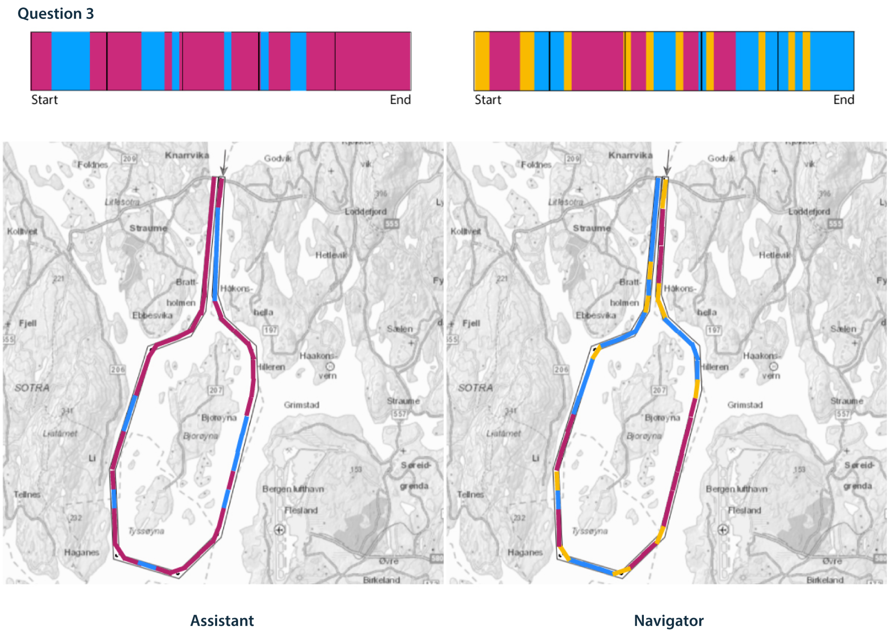


Figure 26: New colored Map - Question 3: environment(blue); instrumentation(red) and teammate(yellow)

7 Discussion

It was a long process to finally come up with the found pattern from the experiment, starting with the understanding of the basics first. Taking notes during the experiment was extremely helpful to understand how navigation in naval high-speed crafts works. Additionally, the results of the questionnaire and the interview supported the observation positively by providing necessary insights into naval bridge-team communication. With this new background information, it was possible to narrow the exercise down into smaller phases to describe what happened. More importantly one can work on the data straight away after the experiment is done and does not need to use technical support to work on it. The results of this initial analysis (chapter 4) became more important during the later manual analysis (chapter 6), helping to sort actions into the predefined phases. However, the results of this first analysis already revealed that there is a repetition in the cadets' actions. Not only the defined phases, e.g. turning, are repeating also the actions of the respective cadets are repeating. Hence the notes are just based on observational skills, it required a profound analysis to back the initial observation up. Therefore, the taken dual-eye-tracking data could be analyzed now. Dual-eye-tracking should reveal even more insights by AOI investigation to determine patterns.

To investigate the AOIs by creating an AOI-time-series diagram was very crucial in the procedure of this thesis. Firstly one has to understand which are the main information sources the Navigator and the Assistant look at, to make any further presumptions on the data. The results from the AOI-time-series diagram also made one aware of the fact, that investigating the less-visited AOIs are more informative in terms of pattern. A less visited AOI is mostly visited when the participant was doing other actions, which implied that patterns can be found more easily in these parts.

Another result was that the Assistant has just two main AOI, making it difficult alone to find patterns. This also indicates that in future studies the AOIs of the Assistant should be more detailed to make better presumptions. However, this would require fundamental knowledge about the system and navigation to be able to understand those actions. Moreover, creating this AOI tables manually was too much time-consuming and it came with imprecise eye-tracking data. Investigating the AOIs on an ECDIS would not be possible with the resolution of the used eye-tracking devices. Future studies should consider a different eye-tracking device, which is more reliable and does come with an analyzing tool.

After the diagram was made, the outcome was not exactly what was being to be expected. In the best case, the outcome should have had already provided some kind of presumption of a possible pattern. Unfortunately, there were just a few cases that were identified as some sort of repetition upon the teams. Interpretation of the diagrams was noticeable difficult and not easy to determine patterns. The only results were shown in Figure 10 and Figure 12, but those did not conclude patterns, hence background knowledge was missing. One cannot identify what is happening by just looking at the AOI itself. In this case, it did not even show a clear tendency of AOI-ratio in specific phases. Therefore the following manual analysis was necessary to further combine previous results. In turn, it was possible to use this data to verify what has been found in the manual analysis, which is a significant outcome. This verification is important, hence it is easy to have the wrong perception when one tries to interpret the situation, especially without an understanding of naval operations.

Just as the creation of the AOI-time-series diagram, the manual analysis was a time-consuming process. It was a similar process, but reduced the fluctuation on the AOI and highlighting the less-visited AOIs. It further helped understand situations by using more AOIs to determine patterns, e.g. movements and non-verbal communication. This workflow was another crucial point that allowed one to understand a situation without exactly understand verbal communication. Another result of this analysis was the great variety of AOIs sequences besides the pattern, which did not match with each other. One can infer that these different behaviors can be due to many factors, such as different levels of navigational skills, workload, the situation, etc. This implies that the reason for the found pattern might correlate to standard procedures from naval education.

8 Conclusion

This study aimed to investigate the possibilities of using dual-eye-tracking to identify patterns in safety-critical systems, more specifically in naval vessel operations. It has been revealed how important it is to use dual eye-trackers to identify AOI and conclude patterns in communication. The patterns inferred that these sequences of AOI for both team-members are probably a duet of eye-movements, most likely to be correlated with each other. This further implies that algorithms should be able to detect those patterns in the future. It might answer the question if dual eye-tracking is necessary or beneficial in such an experiment. On the one hand, the amount of data gets more complex and complicated, on the other hand, it provides so much necessary information that would have been missing to conclude. This study can be seen as an initial attempt to overcome the amount of information, and many possibilities haven't even discovered yet. As written in Chapter 2, there is still not much research on dual eye-tracking so far, this is just the beginning of understanding complex processes from a new perspective. As an example, if one would have had just the data from the Assistant for this case, finding patterns with only two main AOI in the simulator would be challenging, dual-eye-tracking is very important since it compromises actions by other participants.

With this research, it was possible to confirm the phases and notes presumed by the published conference paper (Streilein et al. 2020). By creating manual patterns and the AOI diagrams the same behaviors or patterns in the predicted phases were able to be determined. Even though the manual analysis was just done halfway trough the experiment data, one can assume that the following phases show similar patterns.

It also emerged to be possible to detect communication pattern without a particular focus on verbal communication, due to the data of the dual-eye-tracking. Creating a communication pattern without understanding the content of verbal communication was a difficult situation. As a result, one can also find patterns in communication processes without understanding the language, but still, the actions have to be interpreted somehow. To identify patterns in a different angle or a broader way all various kinds of data streams will be needed and can be added to existing ones. Hopefully, the outcome of this study will be beneficial for researchers who want to investigate communication in the future. This thesis represents the high potential of using dual-eye-tracking for communication purposes outside laboratory environments. As for the design, future applications need to support the user in the best possible way. To design such a system, one has to understand the environment and the user – how does he use the system in this particular environment and how does he interact with it. Obviously, in safety-critical systems users work together as a team, to simply look at the users individually is not enough to create a human-centered design system. Using dual-eye-tracking to investigate communication and vision will become a crucial point in future research.

8.1 Limitations

In the end limitations on this study will be summed up, which might have influenced results and the choice of methods caused by external factors. First, it should be stressed on the fact that as non-Norwegian / non-native speaker, analyzing communication becomes a difficult task, which has to be overcome anyhow. The fact one cannot understand verbal communication restricts one leaving the focus on the non-verbal part of the evaluation. This includes the chance of misinterpreting the situation, which is also caused by the limited understanding of naval navigation.

This leads to another problem, which is the quality of the eye-tracking data. Just six out of the eight experiments were usable for further analysis, but even these have a high gap in data quality. Lacking quality is probably caused by the fact that the used eye-tracking device (Pupil-Labs 2020*a*) was still a beta version. The fact that the simulator was considerably dark made it even more difficult to collect data with these devices.

Even though this study can be determined as a case-study, the sample was very little and the results might not reflect a general behavior. This also comes with the fact that the participants were all young cadets, who might be handling navigation differently and might also have a different level of skills, resulting in different results. Moreover, the situation of the simulator must have been very stressful for the cadets, even though they claimed that it was no problem for them. The simulator was quite small and many external people had watched them doing their simulation, which was at the same time an internal navigation test. All these facts might have had affected the result of eye-tracking and the results.

8.2 Future Research

This research presents a method to give evidence for the existence of naval communication patterns in bridge-team navigation. However, the applied methods in this study are not effective and very time-consuming. Therefore more effective methods should be considered. For future work in particular naval navigation, researchers can consider investigating nearby topics as mentioned in Chapter 2 to investigate the effect of patterns.

When a method is available to profoundly detect patterns effectively, the next step could be the investigation of the impact of workload on the communication pattern. One could identify typical patterns, which occur in a difficult situation (high workload) and compare those to a standard situation (lower workload). With this knowledge, systems could be designed to adjust themself according to the current situation and be able to provide the user with the best user experience and safety.

Another field of interest is the influence of joint vision in communication. Studies should investigate what joint vision of the team members can mean in a team-collaboration. Joint vision might be able to identify good communication patterns, which means researchers were able to find imbalances in communication. A graphic was created by the data from the eye-tracker for later analysis (Appendix A.12), however, it was not discussed in this thesis. Recent studies (Schneider et al. 2018) revealed that joint vision in a learning context is a sign of good communication. Thus, Schneider et al. (2018) was able to find the imbalances of good and bad learning teams out.

These questions could be considered when investigating naval communication:

- How can joint vision be associated with the communication?
- How can joint vision be associated with task features?
- How can joint vision be associated with the outcome (good or bad decision making)

If there would be more research on joint vision in naval bridge team collaboration, one could go further and start investigating effects on joint attention. This could be considered as a direct attempt to improve collaboration and teamwork by letting users see each other's gaze to provide additional team-information.

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A Appendix

A.1 HCI International 2020 - Conference paper

This conference paper got accepted and will be presented in July 2020 at the "HCI International 2020" conference in Copenhagen.

Maritime navigation: Characterizing collaboration in a high-speed craft navigation activity

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Abstract. Communication is an important factor in teamwork and collaboration in safety-critical systems. Operating a safety-critical system such as a military vessel requires maintaining high levels of safety. In maritime navigation, communication is key and collaboration as a team is paramount for safety during navigation. Characterizing this is essential for training and bridge design purposes. Characterizing requires objective tools in addition to visual observation of the navigational exercise. Eye-trackers can fill this gap. Eye-trackers enable measurement of eye movements and dilation measures of the pupil in real time. This can help locate design issues and assist designing training paradigms. In this study two eye-trackers were used to measure joint vision of two navigator simultaneously. Through data of visual attention communication patterns can be characterized with greater richness than just visual observation. As for this case study, in an simulator at the Royal Norwegian Naval Academy in Bergen (Norway), understanding the kind of communication and finding a way to formulate the collaboration will help to characterize communication pattern as a first attempt. This study builds up upon a previous study that improved an off the shelf eye-tracker through hardware additions and software enhancements to accurately measure pupil dilation despite changing ambient light. This study is expected to be a key landmark study that shows the potential of objective tools such as eye-trackers to characterize communication in safety critical systems such as a high-speed navigational environment.

Keywords: maritime · eye-tracker · military vessel · communication · teamwork.

1 Introduction

Communication is key-element of safety-critical systems involving multiple operators, such as navigation of an high-speed military vessel. Efficient bridge teamwork is ensured through precise and established communication. Operations on a military vessel and its performance is highly dependent on the communication (humans interaction) as it is between human-computer interaction. As pointed out by Macrae [8], 42,2% of naval accidents are caused by poor communication between the team members. The recent accident report of the Norwegian Helge Ingstad (frigate) also shows concerns regarding sufficient bridge communication, and failure to build a shared mental model and situational awareness [1].

McCallum [9] notes how sailors do often not ask other crew members for help and often interpret situations on their own; leading to a lack of verified information-flow as more and more things are taken for granted. This behaviour can, therefore, lead to cases such as the accident of Helge Ingstad in 2018 and demonstrates the importance of communication as a tool for improving the team's general awareness of a situation and human errors. Human error happens on the bases of false and incorrect interpretation of the situation; which leads to wrong decision making or improper actions [18]. Therefore, a communication failure can lead to a diverging mental representation of the ship's situation. This representation also has the potential of wrong decision making and might become a safety-critical situation [4].

In the field of control rooms for safety-critical industrial applications, automation is an approach that has proven capable of lowering the chance of human error [2]. Compared to other domains, such as aviation, maritime bridge design still lags in technology adoption [15]. Even though automation should improve the workload during operations, it still has limitations. It can support navigators in their routine, but in case of failure, it can also generate an instant performance demand which could increase stress for the operators [11]. Despite that, it also has been shown that situational awareness could be lowered by the adoption of automation processes [13]. Therefore, the benefits of an automated system depend on how the system is designed or the navigators are trained to overtake in such a safety-critical situation [12]. It is urgent to understand how different situations change human behaviour. The definition of communication patterns is capable of improving the development of automation systems in a safety-critical system such as in military vessels. Prospectively it will help to lower human error and therefore, the safety of the crew.

1.1 Related work

Although the essential communication, in the collaborative environment of safety-critical systems, has been covered by a multitude of studies. For instance, on fields such as aviation and nuclear power plants, showing that understanding and improvement of communication is of high importance[14, 6, 15], there has been a lack of focus on the maritime environment.

A recent study focused on the crew's workload on board of a shipping vessel, including guided tug boats and VTS. It partially shows how communication depends on workload [7]. It is highlighted how communication patterns in the communication dynamics helped to indicate events of interest with a connection to mental workload. Besides conversations recordings (audio analysis), gaze behaviour has shown its importance, as it is associated with performance [16]. This study showed how gaze patterns could measure the performance of athletes in a specific situation, indicating that also gaze tracking could support the analysis of patterns in communication. Weibel et al. [17] have used two wearable eye trackers to track the joint attention of two pilots operating an aeroplane. The study revolves around the development of an effective method to analyze simultaneously multiple data streams in collaboration activities, enabling the tracking of a pilot's behaviour in flight operations. Despite that, Ziv [19] points out that there is still a high demand for analyzing dual (two participants) eye-tracking data. Safety-critical systems often involve more than one operator at a time. Therefore, future research on the topic should focus more on the collaborative aspect as mobile eye-trackers technology becomes more accessible.

1.2 Research question

With this case-study i.e. communication in a military vessel during a navigational activity will be analyzed. The utility of eye-tracking data to understand the communication patterns in this context will also be explored. It will be investigated if the operator's communication can be described and put into a communication pattern in the military vessel background. Using wearable eye-trackers during a routine task will help to get a better understanding of verbal and non-verbal communication. With that as a base, more data can be used to conclude the further behaviour of the operators in that study. The result might be helpful to create new methodologies to evaluate collaboration for training purposes in large vessel simulators.

2 Experiment

2.1 Method background

The experiment has been conducted in collaboration with the Norwegian Defence University College (at the Royal Norwegian Naval Academy in Bergen, Norway), which provided participants (cadets) and use of the simulator facility. Fifteen cadets took part in the experiment plus one member of staff. Each round required two participants (excluding the helmsman) at a time and there were total eight teams. The cadets were graduating students in the operational branch. This implies they have about 300 hours on board the training vessels prior to the data collection.

2.2 Royal Norwegian Navy Simulator

The simulator is equipped with the same Integrated Navigation System (INS) as onboard larger vessels (e.g. Corvettes, Frigates, Submarines or Platform Support Vessel), and is used for navigation training. Figure 1 shows the general setup without the ODB (Optical Bearing Device) lowered. The INS and simulator is provided by a major Original Equipment Manufacturer (OEM), and replicates of the traditional setup with Electronic Chart Display and Information System (ECDIS), Radar, and Conning. The simulator has eight projectors providing a 210 degrees field of view (FOV) in front and 30 degrees FOV astern. For this experiment, the radar was kept off. The team onboard the simulated vessel:

1 **Navigator:** In charge of safe navigation and the leader of the team.
2 **Navigator's Assistant:** Provides the navigator with navigational information, which is aligned with Standard Operating Procedure (SOPs). Conducts nav. tasks for the navigator, e.g. position fixes (are aligned with SOPs).
3 **Helmsman:** responsible for the wheel and throttle of the vessel. Sets speed and steers course as ordered by the navigator.

The Navigator and the Assistant are required to work very closely with explicit closed-loop communication, as neither one of them have the entire picture, thus being dependant on each other. Each run involved two participants, a Navigator and an Assistant. The first run (pilot) involved a staff member as the Assistant. The use of a simulator allows high repeatability of the scenario, traffic and environmental conditions. All experiments were conducted in morning, clear daylight conditions.

2.3 Route

The route starts and ends under the Sotra Bridge near the RNoNA harbour, running clockwise around the Bjorøy island. This route was chosen as it is part of standard training activities and the participants would be in general already familiar to the area. All the participants were given the same navigation plan, which was created by an instructor using standard RNoNA Notations. All Navigators were given five minutes for the team preparation as well as to look through the navigation plan with the Assistant. The scenario was run at the almost constant speed of thirty knots and created with different appearing situations (phases) in order to create a variation in workload:

1 **Phase:** No traffic and easy navigation (baseline).
2 **Phase:** Simple single ship traffic with easy navigation.
3 **Phase:** No traffic and easy navigation (return to baseline).
4 **Phase:** Sudden appearing traffic/near-collision course during narrow and challenging navigation.
5 **Phase:** Complex traffic & easy navigation; the traffic does not require significant actions (compared to phase 4) if the participant acts reasonably.

2.4 Experimental procedure

The experiment was set up in one of the of the simulators of the Royal Norwegian Naval Academy. Data was recorded using multiple devices: overview video of the bridge recorded by a scene camera, eye tracking from both the Navigator and the Assistant (this includes an egocentric video form each participant) and voice recordings.

Fig. 1. Royal Norwegian Navy Simulator in Bergen, assistant (left), navigator (centre) and helmsman (right)

The Pupil Pro eye-tracking glasses[5], was equipped with an egocentric video camera and video tracking of the right eye. It uses infrared technology to record the movement of the eye by the reflecting iris/pupil. Both cadet's eye-movements were recorded at the same time. This particular eye tracker was found suitable for such study as it impedes vision only in minimally thanks to a small eye camera and no frame. The eye-trackers were wired to two different computers with sufficient length to allow the navigator to move freely in the simulator; it has been ensured that the participant would not risk tripping or yanking on the cable. The cadets also were equipped with a clip-on microphone, which wireless recorded each voice separately. Besides the automated data gathering, the experiment involved extensive note-taking and a questionnaire. The questionnaire was administered before the debriefing, and after the session in the simulator. The questionnaire contained questions regarding the route, communication and workload. Most questions were answered by coloring a template of the course.

2.5 Performance Evaluation

The Royal Norwegian Navy (RNoNA) evaluates the performance of high-speed navigation teams by assessing both technical navigation skills (taskwork), and their ability to interact through communication and coordination (teamwork) to support mission objectives. Research on team performance assessment indicates that scoring of performance metrics are best met by balancing teamwork and taskwork constructs [10]. RNoNA subject matter experts have constructed an assessment form that reflects mission essential competencies necessary for safe and efficient high-speed navigation. This observational tool was used to assess each teams' taskwork and teamwork behaviours as they performed the experiment. The route used in the experiment can be broken down into smaller segments labelled with different levels of navigational difficulty. It is expected that teams receiving a low score on observed taskwork and teamwork behaviour within a particular segment also will receive a low score on mission success in the same segment, and vice versa for high performing teams. Additionally, the effect of team performance has on mission success is expected to be more observable in the hardest segments than in segments that are easier to navigate.

2.6 Initial impressions

Emerging communication patterns can be seen in the notes, indicating standardisation in communication and procedures happening on the bridge. Verbal communication is generally preferred to non-verbal. Still, non-verbal communication is used to specify and support verbal communication e.g. to pinpoint dangerous elements in the environment or on the ECDIS. Such instances should have a high chance of joint vision (JV) that will be further investigated. Other cues, such as head movement or eye contact, are used to get attention or confirmation from another crew member. The communication patterns observed during the experiment have been initially organised in four recurring sequences (table 1).

2.7 Future Work

Further analysis of the notes will be followed an integrated with eye-tracking and video recording as well as speech analysis. Areas-of-interest will be used to analyse the eye-tracking data and JV can be identified as the overlap of the dwell time of both navigators. The communication will be analysed through the newly defined pattern set and categorised. Speech analysis and recognition (e.g. words per minute) will be used to support or identify other patters. Still, the content of the conversation will not be analyzed as the content should not correlate with the performance of the operator [20]. The RNoNA will analyze the collected team performance observations with respect to the scores for mission success, both for the overall mission and for each individual segment. It is of interest to the Navy to compare the SME ratings with the data presented by the eye-tracking analysis to identify how eye-tracking tools can assist in performance assessment of teams collaborating in a challenging maritime environment.

Table 1. Observed sequences incl. repeating patterns (N.: Navigator; A.: Assistant)

Briefing	**Initialize**
ECDIS gets inspected Situations are discussed Non-verbal actions to point out situations Set the system and settings e.g. AIS	Check status of everyone N. initialize and takes over the lead Everyone stays in their position Using non-verbal cues (e.g. pointing and look back) A. and N. look often outside
Prepare	**Turning**
A. provides coordinates from ECDIS, N. replies N. uses the Conn and checks other instruments. N. looks outside mostly A looks outside or on ECDIS A wants attention (by pointing or turning head) A. points out a situation (outside)	N. commands the bridge (actively walks around) The voice rises often A looks more often outside and at the N. N. looks together at ECDIS with A. N. mentions s.th outside (both look and discuss) Rarely A. points at the ECDIS (4th turn)
Arrive	
N. mostly stays at middle position Everyone looks mostly outside Non-verbal communication rises A. and N. still discuss situation on ECIDIS	

3 Conclusion

Even though communication frequency may not linearly relate to performance (e.g. an increase of communication may result in an inferior performance [3]), the definition of communication patterns will help to understand how communication can become more or less beneficial in an operational environment. The eye-tracking data should help to quantify the effect of communication on JV and the relation between workload (pupillometry) and other communication variables such as words per minutes. The first outcome of this research is the list of recurring communication patterns extracted from the observation notes. These patterns will be objectively verified through the analysis of the eye-tracking data and speech recordings. This effort should indicate whether such tools can be used to characterize communication in a high-speed navigational environment. Determining standards in communication and procedures could help to identify any abnormal behaviour at an early stage and aid the training process.

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A.2 Experiment: Protocol short version

24.02.2020

Experiment Protocol

Short Protocol

Install devices

1) Computer and Table
- Place computer at a suitable place and find a spot to prepare the papers for the later questionnaire and lay down pens.
- Plug all adapters to power the electronic devices
- Make sure enough space is free on the SSD

2) Microphones: Zoom and Senheiser
1) Turn on Zoom and check batteries
2) Turn on Senheiser and check batteries
    - Connect cables (TC + Zoom, TR+mic)
    - Check wireless connection
3) Check if Zoom audio-recorder receives audio from Sennheiser
4) Check audio sensitivity of the Senheiser microphone

3) Eye-tracker
1) Turn on computer, start needed programs, connect USB to eye-tracker
2) Turn on Eye-tracker and brightness device
3) Check if data get received

4) GoPro
1) Plug GoPro to the USB power-supply
2) Check if SD card has still enough storage (change if necessary)
3) Put on the tripod and check camera angle

Experiment

1) Greeting
1) Greet participants and explain the experiment*
2) Hand out the consent forms and note down experiment No.

2) Prepare
1) Hand out devices (mic and eye-tracker) including the belt to put on
2) Clip mic to the shirt and put all dongles into the belt. Clip ET-cable to the back
3) Start recording all devices: GoPro, Zoom, PupleLab, Brightness-Dongle

3) Start and during the experiment
1) Note down the experiment No. and current time: hold into camera for starting
2) Check if all devices record properly, note down any problems if problem occurs
3) Take notes for observation

Post Experiment

1) Stop recording all devices: GoPro, Zoom, PupleLab, Brightness
2) Take off gear of the participants (mic, belt and eye-tracker)
3) Start questionnaire
    1) Write down No. and mark role
    2) Hand out the questionnaire with provided pens and inks
    3) Provide chocolate to farewell
4) Collect all papers and archive them according to experiment No.
5) Save all data from all electronic devices to external SSD
6) Prepare for next experiment

A.3 Experiment: Completion chart version

Recording		Quality	Video montage export	Audio export	Video analysis	Nmea 2 gpx	WL export	Map Export
1	N	Fair	√	√	√	√	√	√
	A	Very Good	√	√	√	√	√	√
2	N	Good	√	√	√	√	√	√
	A	Fair	√	√	√	√	√	√
3	N	Very Good	√	√	√	√	√	√
	A	Very Good	√	√	√	√	√	√
4	N	Fair	√	√	√	√	√	√
	A	Very Good	√	√	√	√	√	√
5	N	Very Good	√	√	√	√	√	√
	A	Very Good ++	√	√	√	√	√	√
6	N	Fair	√	√	√	√	√	√
	A	Very Good	√	√	√	√	√	√
7	N	Good	√	X (go-pro audio)	√	√	√	√
	A	Very Good ++	√	X (go-pro audio)	√	√	√	√
8	N	Failed	√	√	X	X	X	X
	A	Very Good	√	√	√	√	√	√

Failed: should be discarded

Fair: barely usable and very noisy

Good: Little noise and tracking losses

Very Good: Doesn't get better than this

A.4 Experiment: Questionnaire

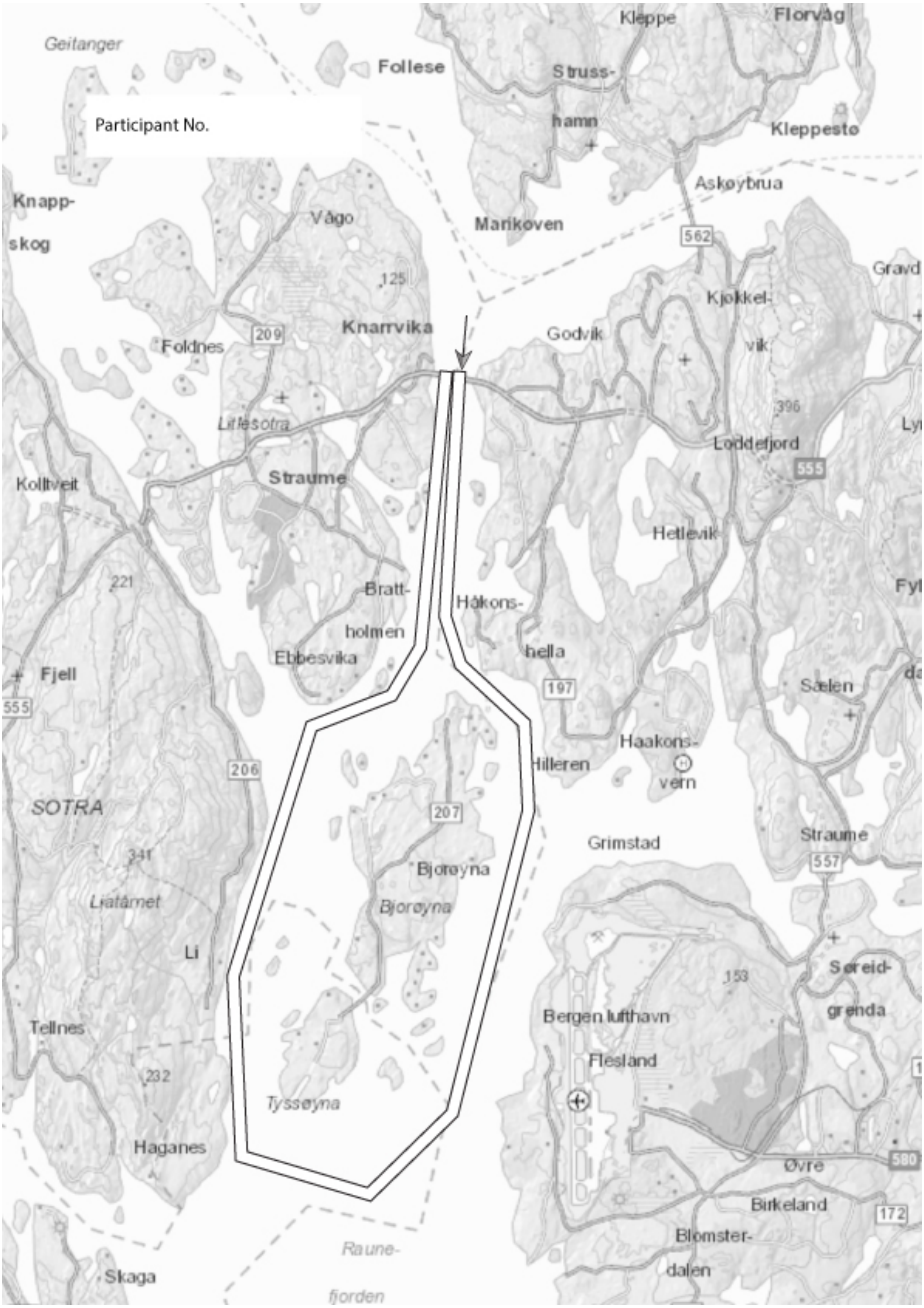
Participant n°_________

O Navigator   O Assistant

Question 1 of 5

Indicate the workload during the navigational course. Use the color references below for the level of workload.

- Use **BLUE** to mark areas of **below average** workload.
- Use **PURPLE** to mark areas of **average** workload.
- Use **ORANGE** to mark areas of **above average** workload.


Participant No.
Geitanger
Follese
Kleppe
Florvåg
Struss-
hamn
Kleppestø
Askøybrua
Knapp-
skog
Vågo
Marikoven
562
125
Gravd
Kjøkkel-
vik
Godvik
Knarrvika
209
Foldnes
Littlesotra
396
Loddefjord
555
Straume
Kolltveit
Hetlevik
221
Bratt-
holmen
Håkons-
hella
Ebbesvika
Fjell
555
197
Sælen
Haakons-
vern
Hilleren
206
SOTRA
207
Grimstad
Straume
557
341
Bjorøyna
Liatåmet
Bjorøyna
Li
153
Søreid-
grenda
Bergen lufthavn
Tellnes
Flesland
232
Tyssøyna
Haganes
580
Øvre
Birkeland
172
Blomster-
dalen
Raune-
fjorden
Skaga

How frequently you require information from your teammate? Indicate the frequency with the color references provided below.

- Use **BLUE** to mark areas where you **do not require** information from the teammate.
- Use **PURPLE** to mark areas where you **sporadically require** information from the teammate.
- Use **ORANGE** to mark areas where you **often require** information from the teammate.

Question 3 of 5

What is your primary source of information during the navigational course? Use color references below to indicate the same.

- Use **BLUE** to mark areas where **the environment** is the primary source.
- Use **PURPLE** to mark areas where **the instrumentation** is the primary source.
- Use **ORANGE** to mark areas where your **teammate** is the primary source.

Did you receive sufficient information during the navigational course? (all sources) Indicate the sufficiency with the color references provided below.

- Use **BLUE** to mark areas where you **did not receive** sufficient information.
- Use **PURPLE** to mark areas where you **receive all necessary** information.
- Use **ORANGE** to mark areas where you **received too much** information.

Question 5 of 5

Mark the critical sections on the map with **RED color** where communication with your teammate was particularly important, **if ever.**

Please briefly describe why.

A.5 NSD's Assessment

NORSK SENTER FOR FORSKNINGSDATA

NSD's assessment

Project title

Understanding communication in a collaborative team navigation on a high-speed craft by using two eye-tracker

Reference number

726889

Registered

21.01.2020 av Tim Streilein - timst@stud.ntnu.no

Data controller (institution responsible for the project)

Norges teknisk-naturvitenskapelige universitet NTNU / Fakultet for arkitektur og design (AD) / Institutt for design

Project leader (academic employee/supervisor or PhD candidate)

Frode Volden, frodv@ntnu.no, tlf: 93227262

Type of project

Student project, Master’s thesis

Contact information, student

Tim Streilein, timst@stud.ntnu.no, tlf: 4915772157442

Project period

01.01.2020 - 28.02.2022

Status

14.02.2020 - Assessed

Assessment (1)

14.02.2020 - Assessed

Our assessment is that the processing of personal data in this project will comply with data protection legislation, so long as it is carried out in accordance with what is documented in the Notification Form and attachments, dated 14.02.2020, as well as in correspondence with NSD. Everything is in place for the processing to begin.

NOTIFY CHANGES
If you intend to make changes to the processing of personal data in this project it may be necessary to notify NSD. This is done by updating the information registered in the Notification Form. On our website we

explain which changes must be notified. Wait until you receive an answer from us before you carry out the changes.

TYPE OF DATA AND DURATION
The project will be processing general categories of personal data until 28.02.2022. All personal data will then be anonymized/deleted. The informed consents will however be kept locked in physical form for up to three years.
LEGAL BASIS
The project will gain consent from data subjects to process their personal data. We find that consent will meet the necessary requirements under art. 4 (11) and 7, in that it will be a freely given, specific, informed and unambiguous statement or action, which will be documented and can be withdrawn. The legal basis for processing personal data is therefore consent given by the data subject, cf. the General Data Protection Regulation art. 6.1 a).

PRINCIPLES RELATING TO PROCESSING PERSONAL DATA
NSD finds that the planned processing of personal data will be in accordance with the principles under the General Data Protection Regulation regarding:

- lawfulness, fairness and transparency (art. 5.1 a), in that data subjects will receive sufficient information about the processing and will give their consent
- purpose limitation (art. 5.1 b), in that personal data will be collected for specified, explicit and legitimate purposes, and will not be processed for new, incompatible purposes
- data minimisation (art. 5.1 c), in that only personal data which are adequate, relevant and necessary for the purpose of the project will be processed
- storage limitation (art. 5.1 e), in that personal data will not be stored for longer than is necessary to fulfil the project's purpose

THE RIGHTS OF DATA SUBJECTS
Data subjects will have the following rights in this project: transparency (art. 12), information (art. 13), access (art. 15), rectification (art. 16), erasure (art. 17), restriction of processing (art. 18), notification (art. 19), data portability (art. 20). These rights apply so long as the data subject can be identified in the collected data.

NSD finds that the information that will be given to data subjects about the processing of their personal data will meet the legal requirements for form and content, cf. art. 12.1 and art. 13.

We remind you that if a data subject contacts you about their rights, the data controller has a duty to reply within a month.

FOLLOW YOUR INSTITUTION'S GUIDELINES
NSD presupposes that the project will meet the requirements of accuracy (art. 5.1 d), integrity and confidentiality (art. 5.1 f) and security (art. 32) when processing personal data.

To ensure that these requirements are met you must follow your institution's internal guidelines and/or consult with your institution (i.e. the institution responsible for the project).

FOLLOW-UP OF THE PROJECT
NSD will follow up the progress of the project underway (every other year) and at the planned end date in order to determine whether the processing of personal data has been concluded/is being carried out in accordance with what is documented.

Good luck with the project!

Contact person at NSD: Jørgen Wincentsen
Data Protection Services for Research: +47 55 58 21 17 (press 1)

A.6 NSD: Consent Form

Are you interested in taking part in the research project

”Investigating mental workload by using eye tracker during collaborative operations in a maritime setup”?

This is an inquiry about participation in a research project where the main purpose is investigate the use of eye-tracking technology in human factors engineering and usability testing with a specific focus on field studies. In this letter we will give you information about the purpose of the project and what your participation will involve.

Purpose of the project
The proposed project aims to investigate the use of eye-tracking technology in human factors engineering and usability testing with a specific focus on field studies. The data we are collecting in this phase will help us validate a method that estimates the pupil size as it changes over time for a given luminose stimuli.

The proposed project will also investigate the communication and collaboration between operators in a safety critical system. Eye tracker data from both participants will be used to track the joint visual attention and communication inside the team and better understand communication in a safety critical operation.

Who is responsible for the research project?

Supervisor Frode Volden
frodv@ntnu.no
NTNU Norges teknisk-naturvitenskapelige universitet / Institutt for design
tel +47 93227262

Supervisor Sashidharan Komandur
sashidharan.komandur@ntnu.no
tel +47 938 39 222
NTNU Norges teknisk-naturvitenskapelige universitet / Institutt for design

Research Assistant Giovanni Pignoni
giovanni.pignoni@ntnu.no
tel +47 46904106

Student Tim Streilein
timst@stud.ntnu.no

Why are you being asked to participate?
You have been selected as a cadet of the Royal Norwegian Naval Academy

What does participation involve for you?
Participation to the study will require the subject to wear an eye tracking device while performing normal operation on board a simulated vessel bridge. After the test, the participant will be presented with a visual representation of the course and will be asked to answer a questionnaire on the cognitive workload they experienced and other relevant information. The participants will be interviewed about the communication dynamics in the crew and crew's teamwork. The subjects will be provided with the opportunity for a debriefing in which he/she will be able to ask further questions to the team regarding the research. The eye tracker will record a video feed of the participant right eye and from the point of view of the participant. A "third person" camera will record the operation as well as audio during the experiment. The researcher will perform a pre-test screening to evaluate if the participant respects the selected criteria and reserve the possibility to interrupt the interview at any moment.

Participation is voluntary
Participation in the project is voluntary. If you chose to participate, you can withdraw your consent at any time without giving a reason. All information about you will then be made anonymous. There will be no negative consequences for you if you chose not to participate or later decide to withdraw.

Your personal privacy – how we will store and use your personal data
We will only use your personal data for the purpose(s) specified in this information letter. We will process your personal data confidentially and in accordance with data protection legislation (the General Data Protection Regulation and Personal Data Act).
You will not be identified in any reports on this study. This study is anonymous. We will not be collecting or retaining any information about your identity or that could indirectly identify you. The records of this study will be kept strictly confidential. The raw eye tracking data and video recordings will be stored until the end of the research (February 2022), and anonymised or deleted afterwards. It is voluntary to participate, and you can at any time withdraw your consent without starting the reason, personal data can be deleted upon request of the participant until the anonymisation has taken place. Contact giovanni.pignoni@ntnu.no to ask for the removal of your personal data before the end of the study.

What will happen to your personal data at the end of the research project?
The received data will anonymised or deleted after the completion of the study at the latest 28th February 2022.
The data will be stored on an encrypted external hard drive in a locked facility, only the Researcher and Supervisor will have access to the data.
The informed consents will be kept in physical form, stored in a locked facility for up to three years after the completion of the study (27th February 2025).

Your rights
So long as you can be identified in the collected data, you have the right to:
- access the personal data that is being processed about you
- request that your personal data is deleted
- request that incorrect personal data about you is corrected/rectified
- receive a copy of your personal data (data portability), and

- send a complaint to the Data Protection Officer or The Norwegian Data Protection Authority regarding the processing of your personal data

Given the nature of the anonymised data, it will be impossible to request a correction of the samples, it will be possible to ask for deletion of the data, contact the Principal Investigator for further information regarding the handling of your data.
Frode Volden frodv@ntnu.no tel +47 93227262

What gives us the right to process your personal data?
We will process your personal data based on your consent.

Based on an agreement with NTNU, NSD – The Norwegian Centre for Research Data AS has assessed that the processing of personal data in this project is in accordance with data protection legislation.

Where can I find out more?
If you have questions about the project, or want to exercise your rights, contact:

- NTNU Norges teknisk-naturvitenskapelige universitet / Institutt for design via "Frode Volden".
- Our Data Protection Officer: "Thomas Helgesen"
- NSD – The Norwegian Centre for Research Data AS, by email: (personverntjenester@nsd.no) or by telephone: +47 55 58 21 17.

Yours sincerely,

Frode Volden	Sashidharan Komandur	Giovanni Pignoni	Tim Streilein
(Researcher/supervisor)	(Researcher/supervisor)	(Research Assistant)	(Student)

Consent form

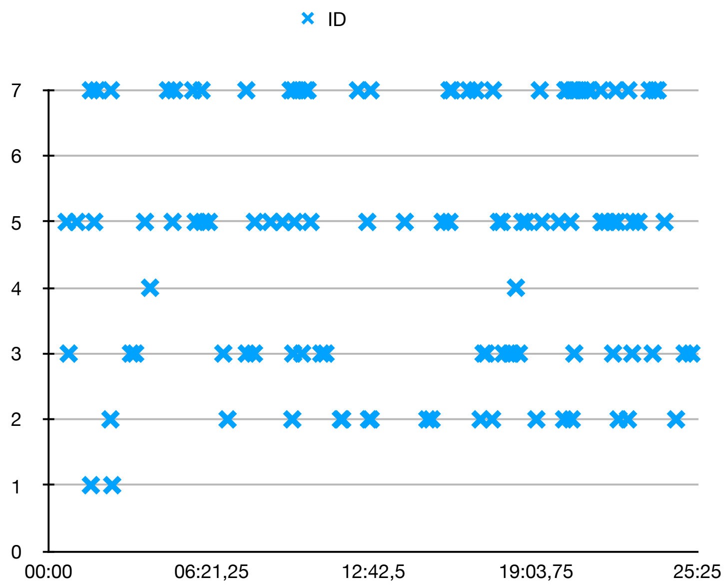
I have received and understood information about the project "Development of a quantitative evaluation tool of cognitive workload in field studies through eye tracking." and have been given the opportunity to ask questions. I give consent:

- ☐ to participate in *the eye tracking experiment,*
- ☐ *for my personal data to be processed un Norway.*

I give consent for my personal data to be processed until the end date of the project, approx 28th February 2022.

(Signed by participant, date)

A.7 Table: Non-verbal interactions



Non_verbal Communication

		TIME	ID	Team 1	Team 2	Team 3	Team 4	Team 5	Team 7
01:39		01:39	1	points finger _ no JVA					
02:29		02:29	1	points - finger not seen					
02:25		02:25	2		AS Handsign				
07:00		07:00	2		AS guckt raus - NV hinterher				
09:32		09:32	2		AS Handsign				
11:26	**11:27**	11:26	2		AS Hand Out JVA				
11:29	**11:30**	11:29	2		AS Hand Out JVA				
12:32	**12:33**	12:32	2		AS Hand Out JVA				
12:36	**12:37**	12:36	2		AS Hand Out JVA				
14:49	**14:58**	14:49	2		AS Hand ECDIS JVA				
14:59	**15:04**	14:59	2		AS Hand ECDIS JVA				
16:54		16:54	2		AS Hand sign				
16:56	**16:58**	16:56	2		AS Hand PM				
17:21		17:21	2		AS Hand sign				
19:05		19:05	2		AS Hand sign				
20:10		20:10	2		AS Hand sign				
20:28	**20:30**	20:28	2		AS Hand PO JVA				
22:18		22:18	2		AS Hand sign				
22:40		22:40	2		AS Hand sign				
24:33		24:33	2		AS Hand sign				
00:47		00:47	3			AS looks away			
03:13		03:13	3			NV Hand sign			
03:23		03:23	3			NV Hand sign			
06:50		06:50	3			NV Hand sign			
07:45		07:45	3			NV Hand sign			
08:02		08:02	3			NV steps for			

		TIME	ID	Team 1	Team 2	Team 3	Team 4	Team 5	Team 7
09:34		09:34	3			NV steps for			
09:55		09:55	3			NV Hand sign			
10:40		10:40	3			AS looks NV			
10:50		10:50	3			AS looks NV			
17:01		17:01	3			NV steps for projection			
17:07		17:07	3			AS leans back			
17:48		17:48	3			NV steps for			
18:04		18:04	3			AS Hand Sign			
18:07		18:07	3			AS Hand Sign			
18:24		18:24	3			NV Hand sign			
20:34		20:34	3			NV Hand sign			
22:05		22:05	3			NV Hand sign			
22:50		22:50	3			AS looks NV			
23:38		23:38	3			NV Hand sign			
24:53		24:53	3			AS looks NV			
25:09		25:09	3			AS looks NV			
03:58		03:58	4				NV Hand sign		
18:17		18:17	4				NV Hand sign		
00:42		00:42	5					NV comes front	
01:06		01:06	5					NV comes front	
01:08		01:08	5					As Finger pointing	
01:47		01:47	5					NV moving	
03:46		03:46	5					NV comes front	
03:47		03:47	5					As Finger pointing	
04:51		04:51	5					NV moving	
05:45		05:45	5					NV comes front	
06:02		06:02	5					NV goes to HM	
06:16		06:16	5					NV comes front	
08:04		08:04	5					NV moving	
08:41		08:41	5					NV comes front screen	
09:09		09:09	5					NV goes to HM	
09:37		09:37	5					NV comes front	
10:15		10:15	5					NV comes front	
12:28		12:28	5					As Finger pointing Nv comes front	
13:56		13:56	5					As Finger pointing Nv comes front	
15:25		15:25	5					NV finger pointing	
15:41		15:41	5					As Finger pointing Nv comes front	
17:37		17:37	5					As Finger pointing Nv comes front	
17:44		17:44	5					As looks right	
18:32		18:32	5					NV comes front	
18:41		18:41	5					NV comes front	
18:42		18:42	5					As Finger pointing	
19:18		19:18	5					NV comes front to see screen	
19:58		19:58	5					NV comes front	

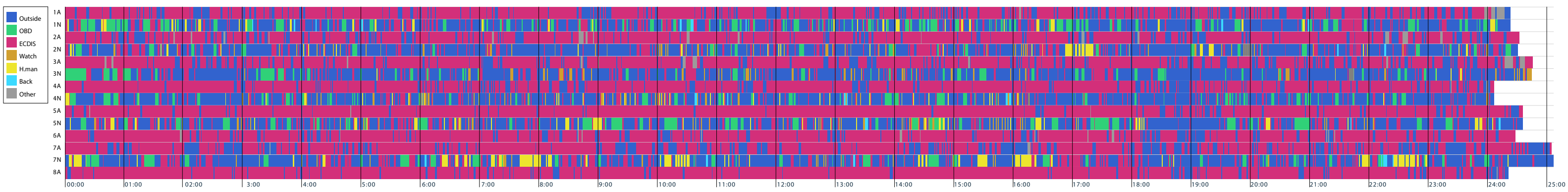
		TIME	ID	Team 1	Team 2	Team 3	Team 4	Team 5	Team 7
20:25		20:25	5					NV comes front to see screen	
20:26		20:26	5					As Finger pointing	
21:38		21:38	5					NV comes front	
21:41		21:41	5					NV finger pointing	
21:52		21:52	5					NV comes front and finger points	
22:05		22:05	5					NV comes front	
22:15		22:15	5					NV comes front	
22:51		22:51	5					NV comes front	
23:05		23:05	5					NV comes front and finger points	
24:06		24:06	5					NV comes front	
01:39		01:39	7						AS point screen
01:54		01:54	7						NV + AS point screen
02:26		02:26	7						AS point screen
04:40		04:40	7						AS point screen
04:55		04:55	7						NV + AS point screen
05:39		05:39	7						AS point screen - NV no reaction
05:59		05:59	7						NV point screen
07:44		07:44	7						NV to HM
09:28		09:28	7						NV comes front to see screen
09:35		09:35	7						NV comes front to see screen
09:48		09:48	7						As points out
10:03		10:03	7						AS point screen
10:08		10:08	7						NV point out
12:06		12:06	7						As points out (no visible in cam but NV noticed)
12:36		12:36	7						AS point screen
15:41		15:41	7						AS point screen
15:47		15:47	7						NV to HM
16:26		16:26	7						NV to HM
16:43		16:43	7						AS point screen
17:23		17:23	7						AS point screen (ship?)
19:13		19:13	7						As points out (ship?)
20:13		20:13	7						NV + AS point screen
20:17		20:17	7						NV point out
20:30		20:30	7						AS point screen
20:34		20:34	7						NV point out
20:35		20:35	7						NV point out
20:36		20:36	7						NV point screen
20:52		20:52	7						As points out
21:06		21:06	7						AS point screen
21:12		21:12	7						AS point screen
21:36		21:36	7						AS point screen
21:38		21:38	7						As points out

		TIME	ID	Team 1	Team 2	Team 3	Team 4	Team 5	Team 7
22:11		22:11	7						As points out
22:12		22:12	7						AS point screen (get ignored)
22:41		22:41	7						AS point screen (get ignored)
23:31		23:31	7						As points out
23:44		23:44	7						As points out
23:50		23:50	7						AS point screen (NV comes later)

A.8 Diagram: AOI-Time: Teams grouped

This diagram is in Pdf format - to look closer zoom in.

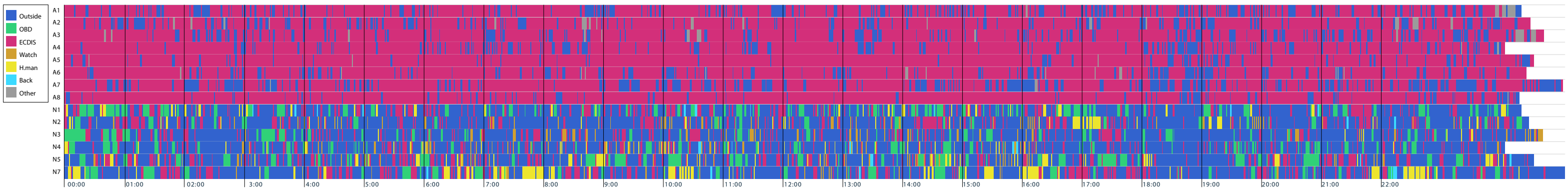
1. AOI - Time diagram: teams grouped



A.9 Diagram: AOI-Time: Position grouped

This diagram is in Pdf format - to look closer zoom in.

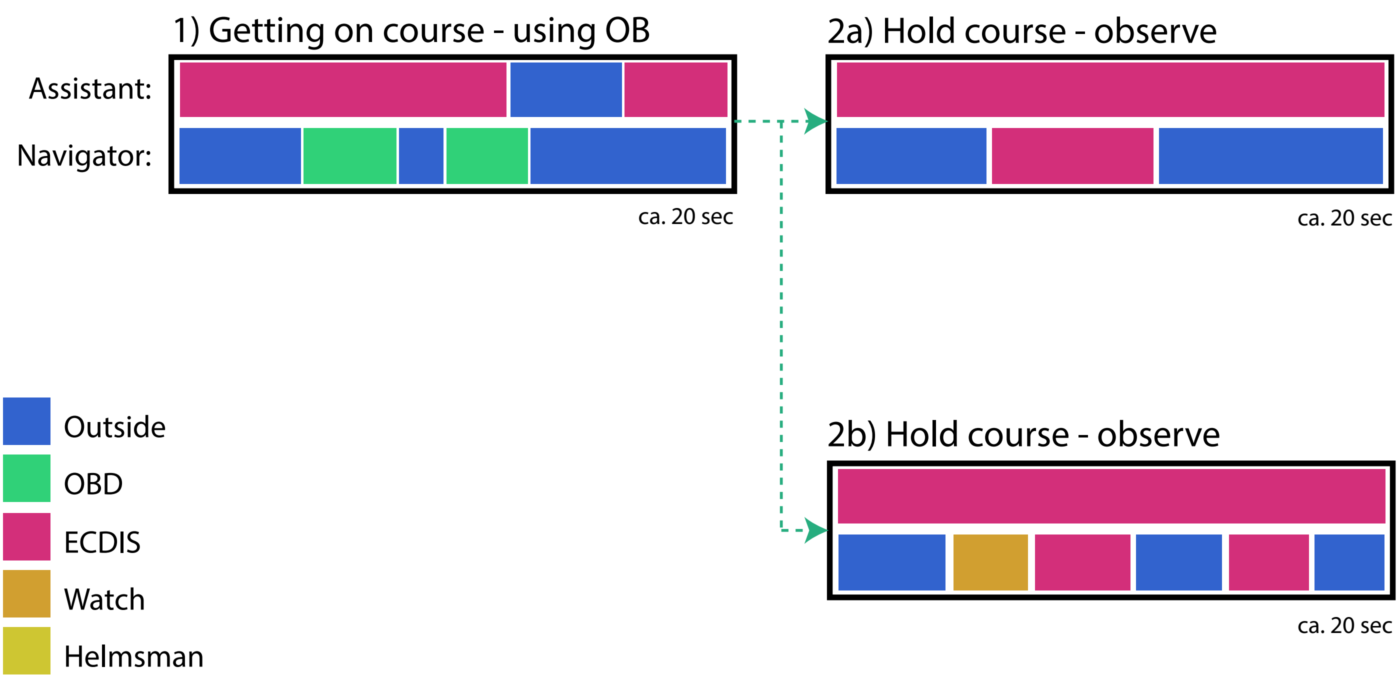
2. AOI - Time diagram: Position grouped



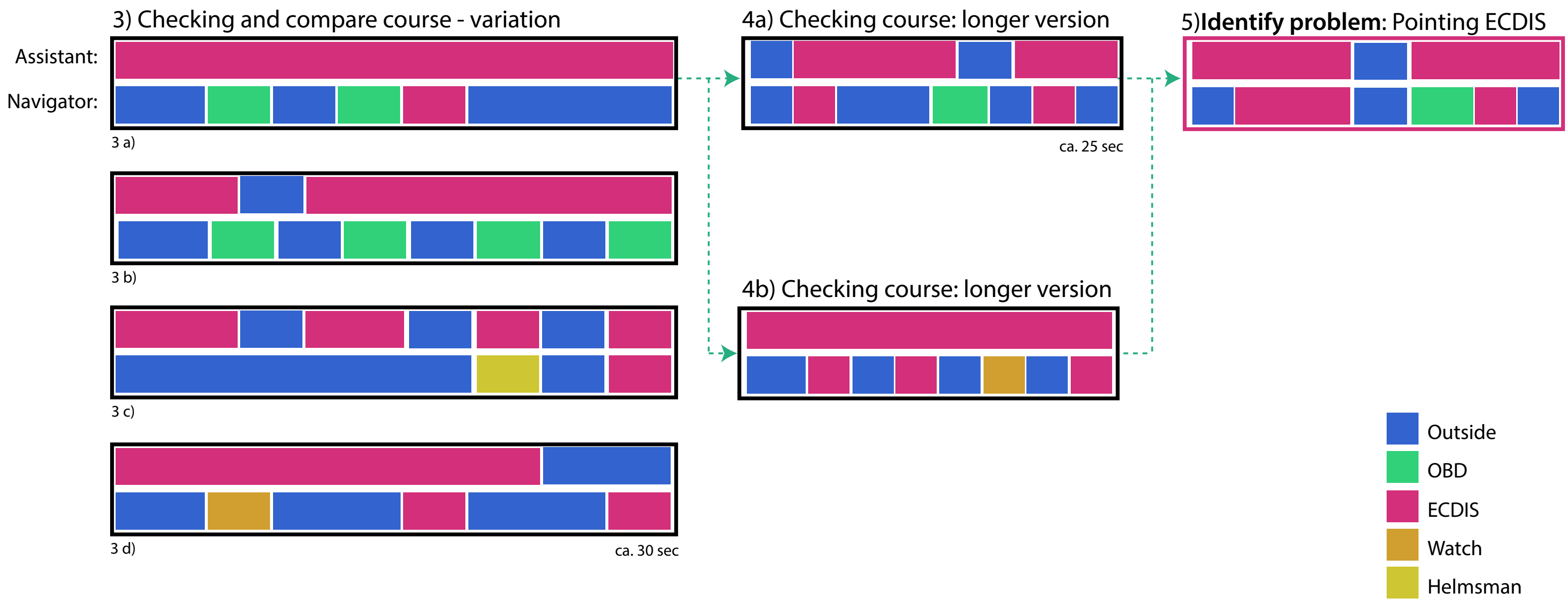
A.10 Pattern: Overview

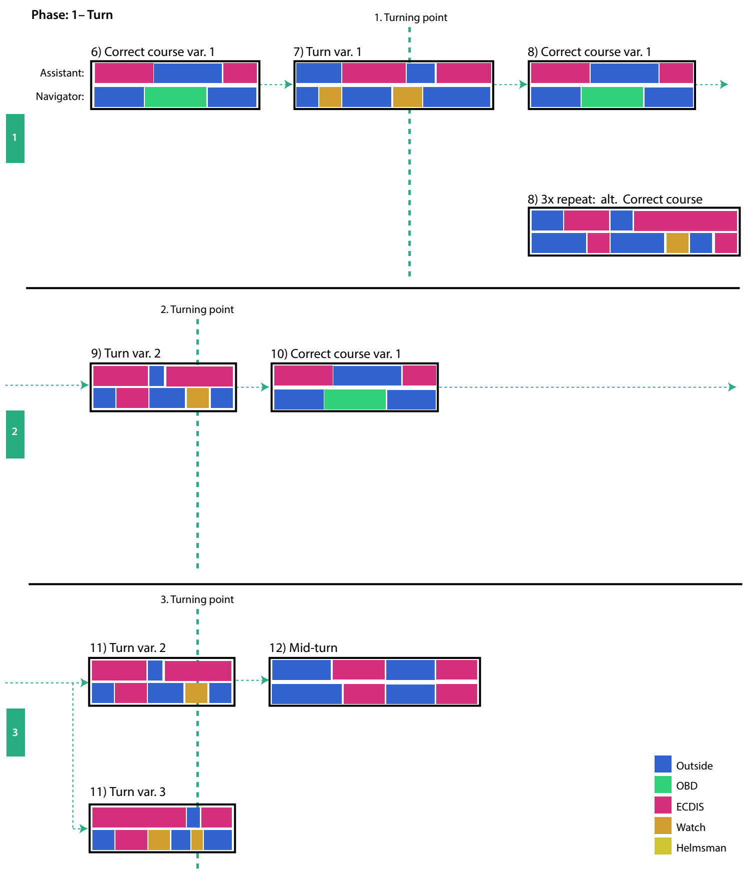
This diagram is in Pdf format - to look closer zoom in.

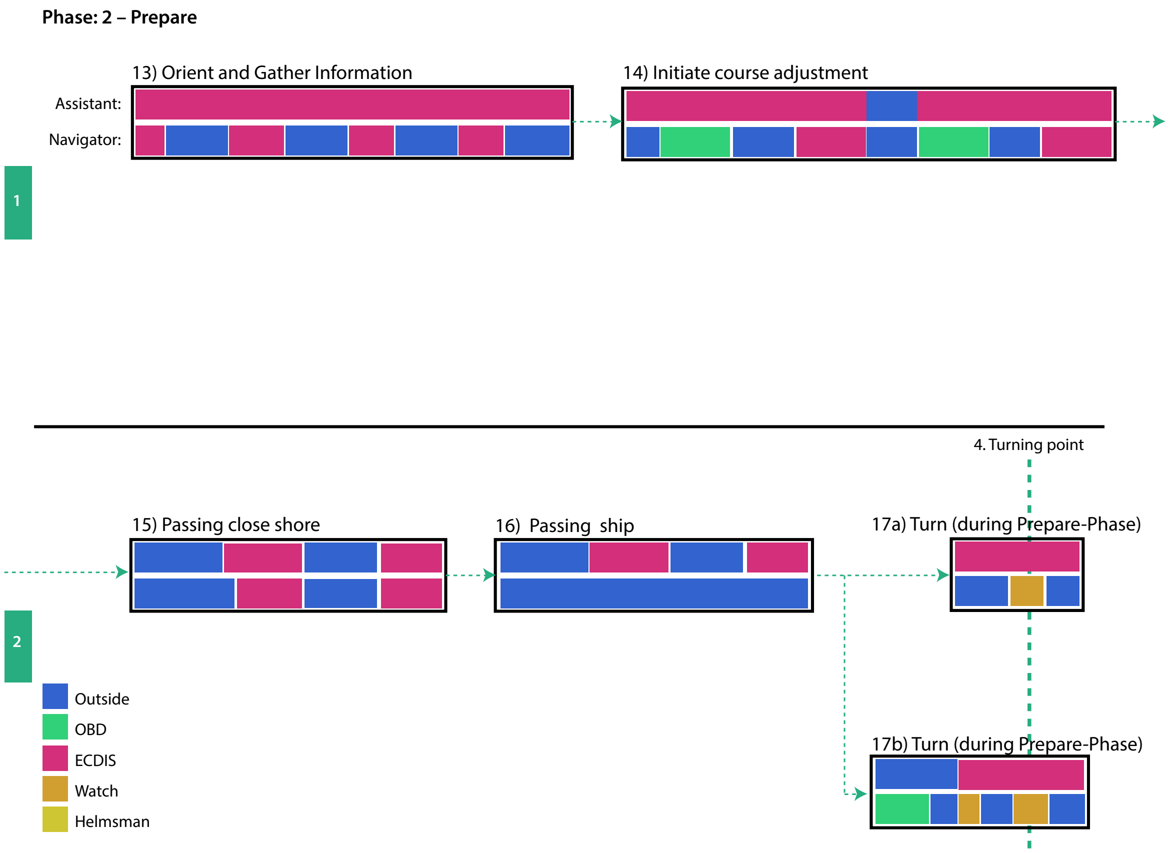
Phase: Initialize



Phase: 1 - Prepare

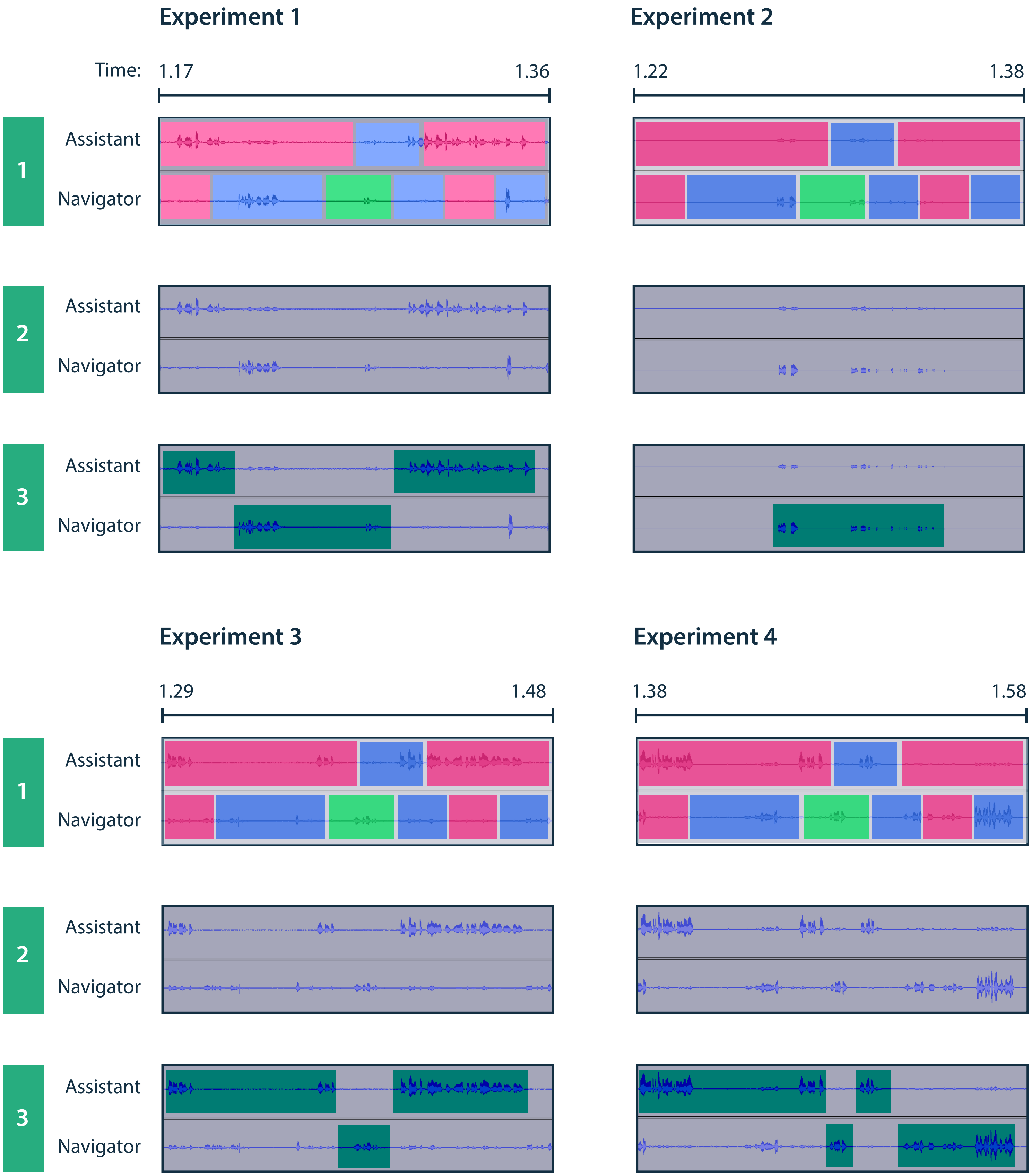



Phase: 1– Turn
1. Turning point
6) Correct course var. 1
7) Turn var. 1
8) Correct course var. 1
Assistant:
Navigator:
1
8) 3x repeat: alt. Correct course
2. Turning point
9) Turn var. 2
10) Correct course var. 1
2
3. Turning point
11) Turn var. 2
12) Mid-turn
3
11) Turn var. 3
Outside
OBD
ECDIS
Watch
Helmsman


Phase: 2 – Prepare
13) Orient and Gather Information
14) Initiate course adjustment
Assistant:
Navigator:
1
4. Turning point
15) Passing close shore
16) Passing ship
17a) Turn (during Prepare-Phase)
17b) Turn (during Prepare-Phase)
2
Outside
OBD
ECDIS
Watch
Helmsman

A.11 Pattern: Audio overlay

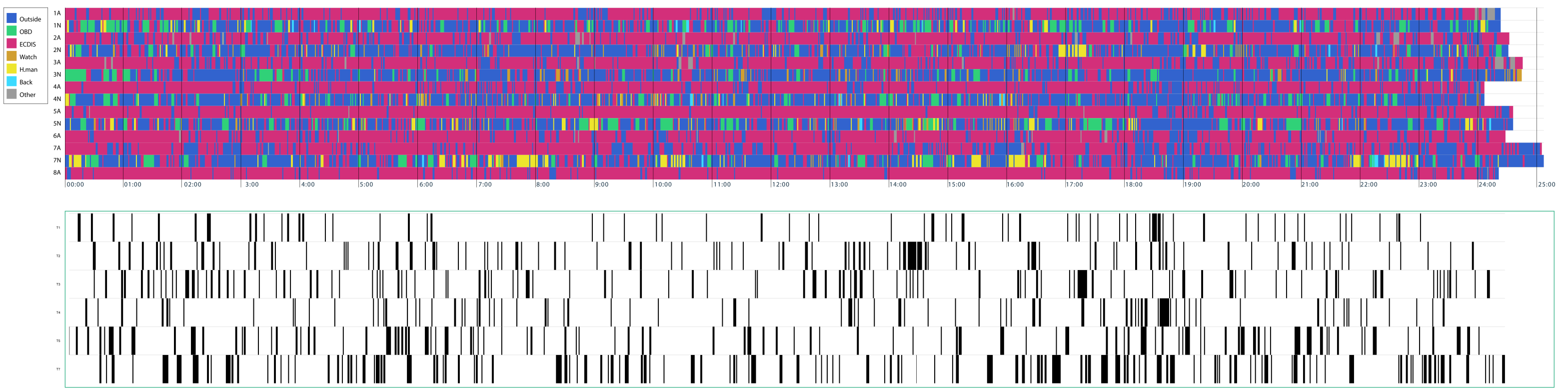
This diagram is in Pdf format - to look closer zoom in.


Experiment 1
Experiment 2
Time:
1.17
1.36
1.22
1.38
1
Assistant
Navigator
2
Assistant
Navigator
3
Assistant
Navigator
Experiment 3
Experiment 4
1.29
1.48
1.38
1.58
1
Assistant
Navigator
2
Assistant
Navigator
3
Assistant
Navigator

A.12 Joint vision vs AOI-Time

This diagram is in high resolution PNG format - to look closer zoom in.

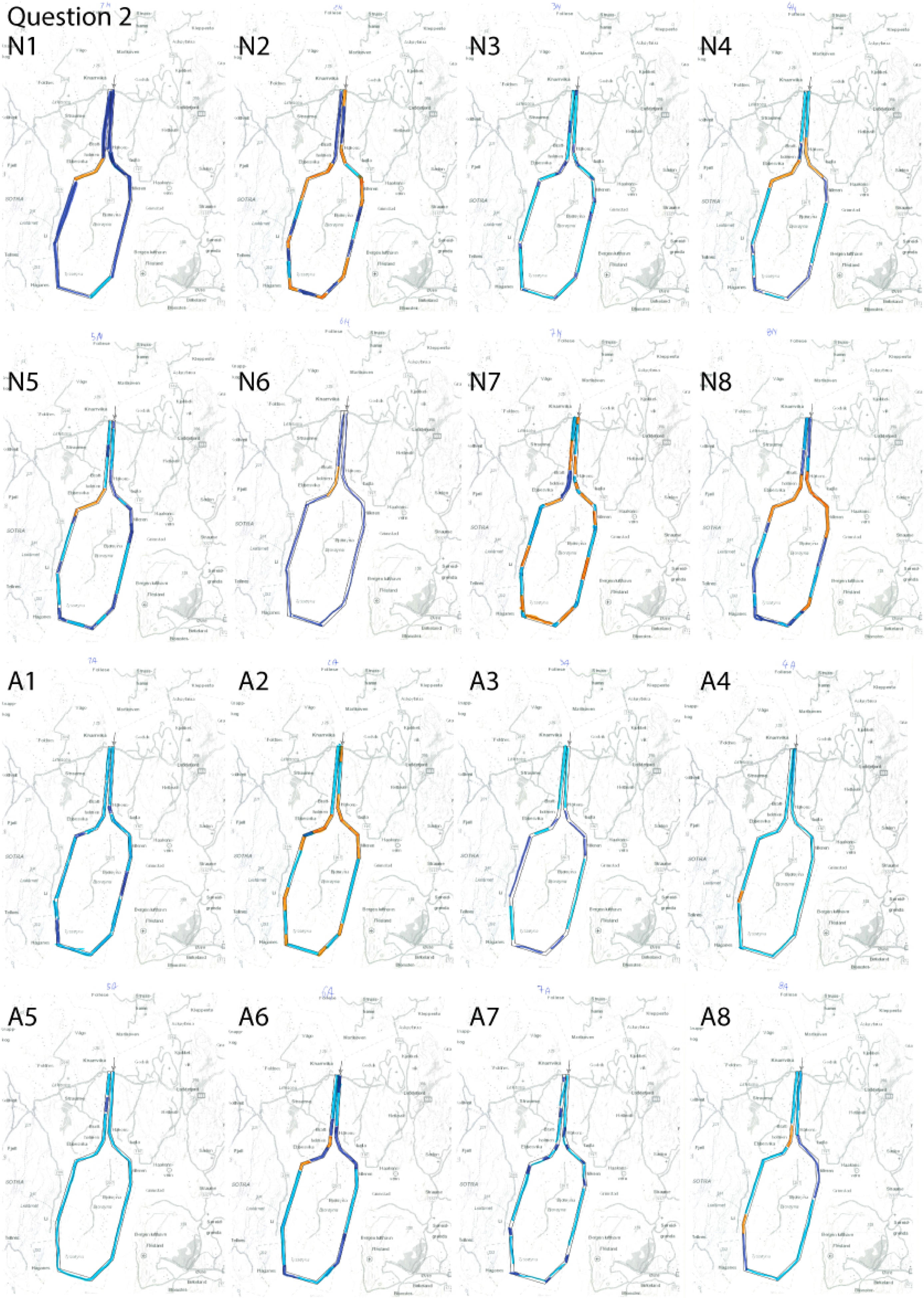
1. AOI - Time diagram vs Joint vision



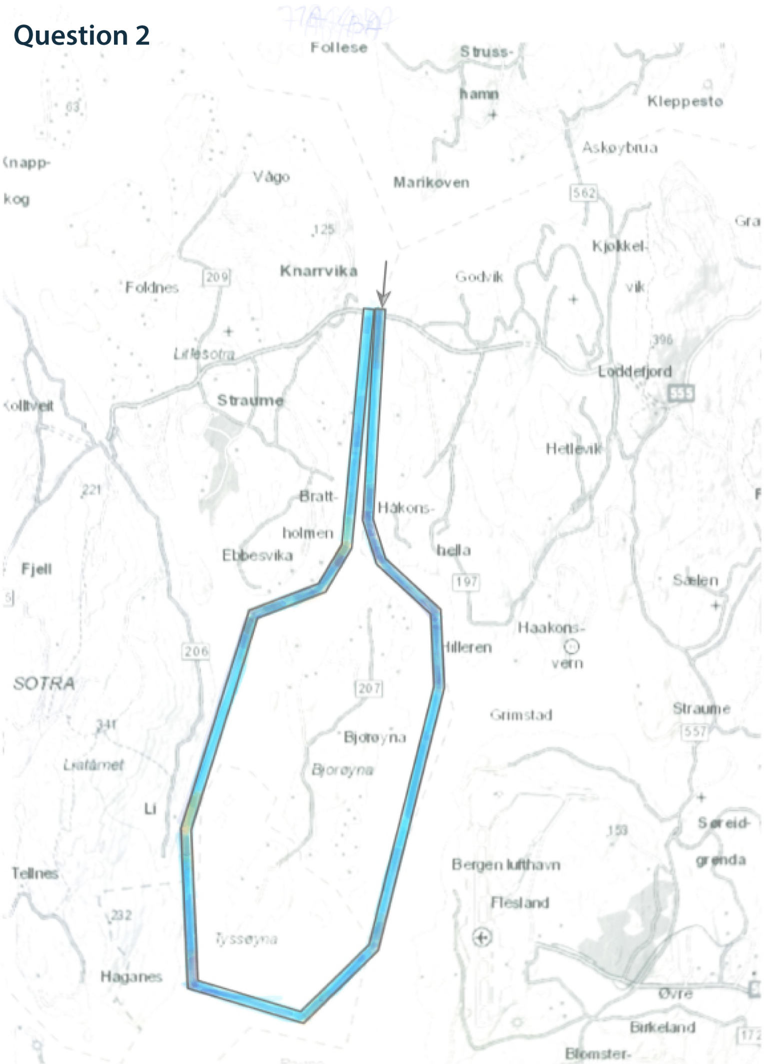
A.13 Questionnaire: Colored Map

This diagram is in high resolution PDF format - to look closer zoom in.

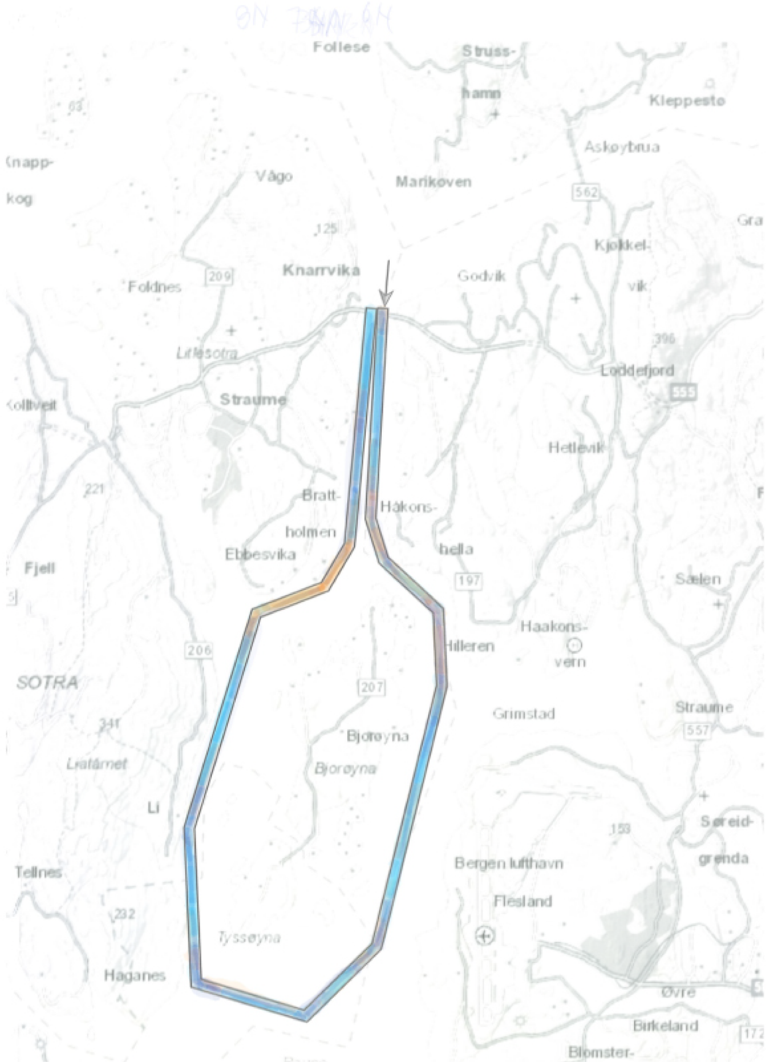
Question 2



Question 2

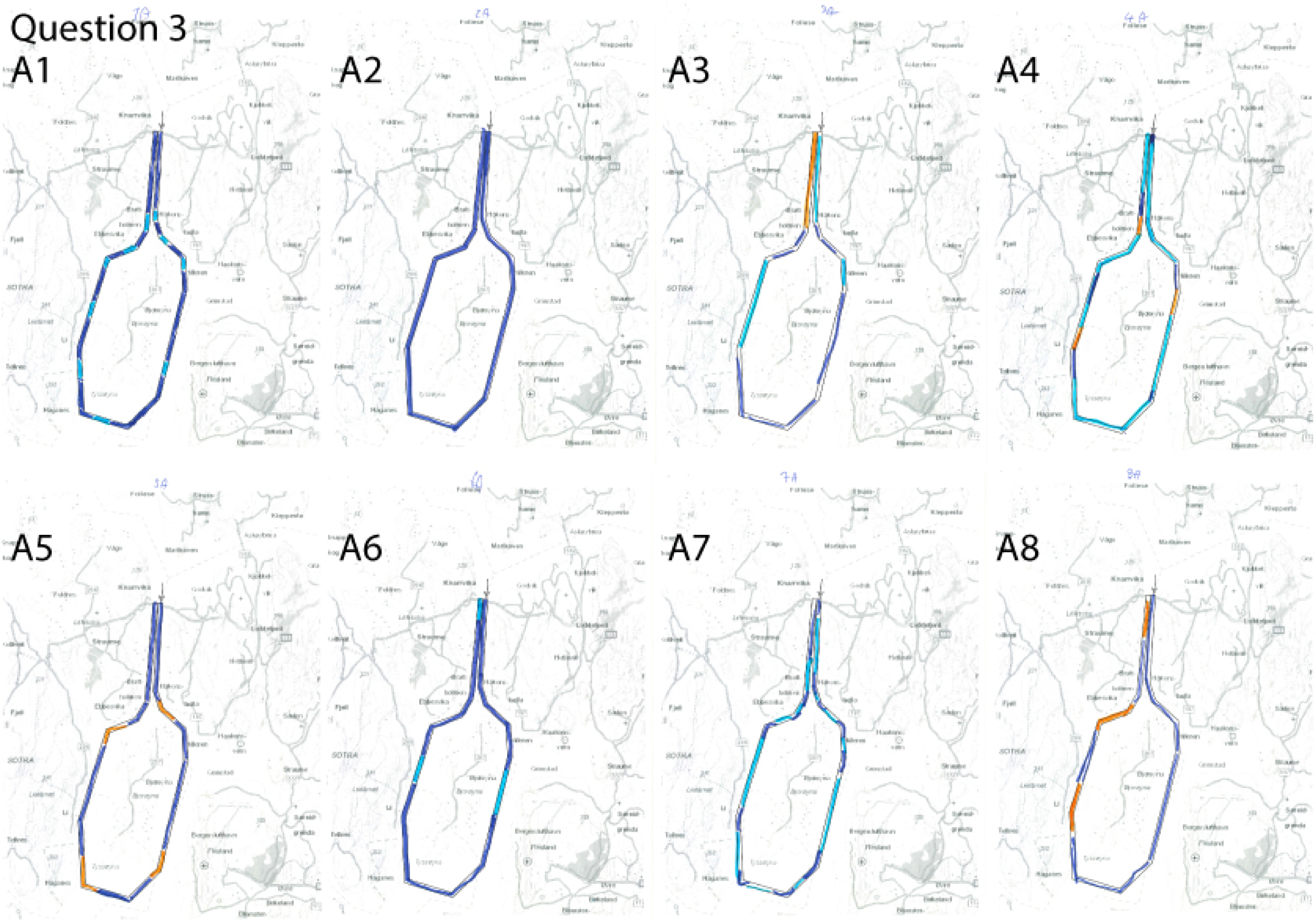


Assistant

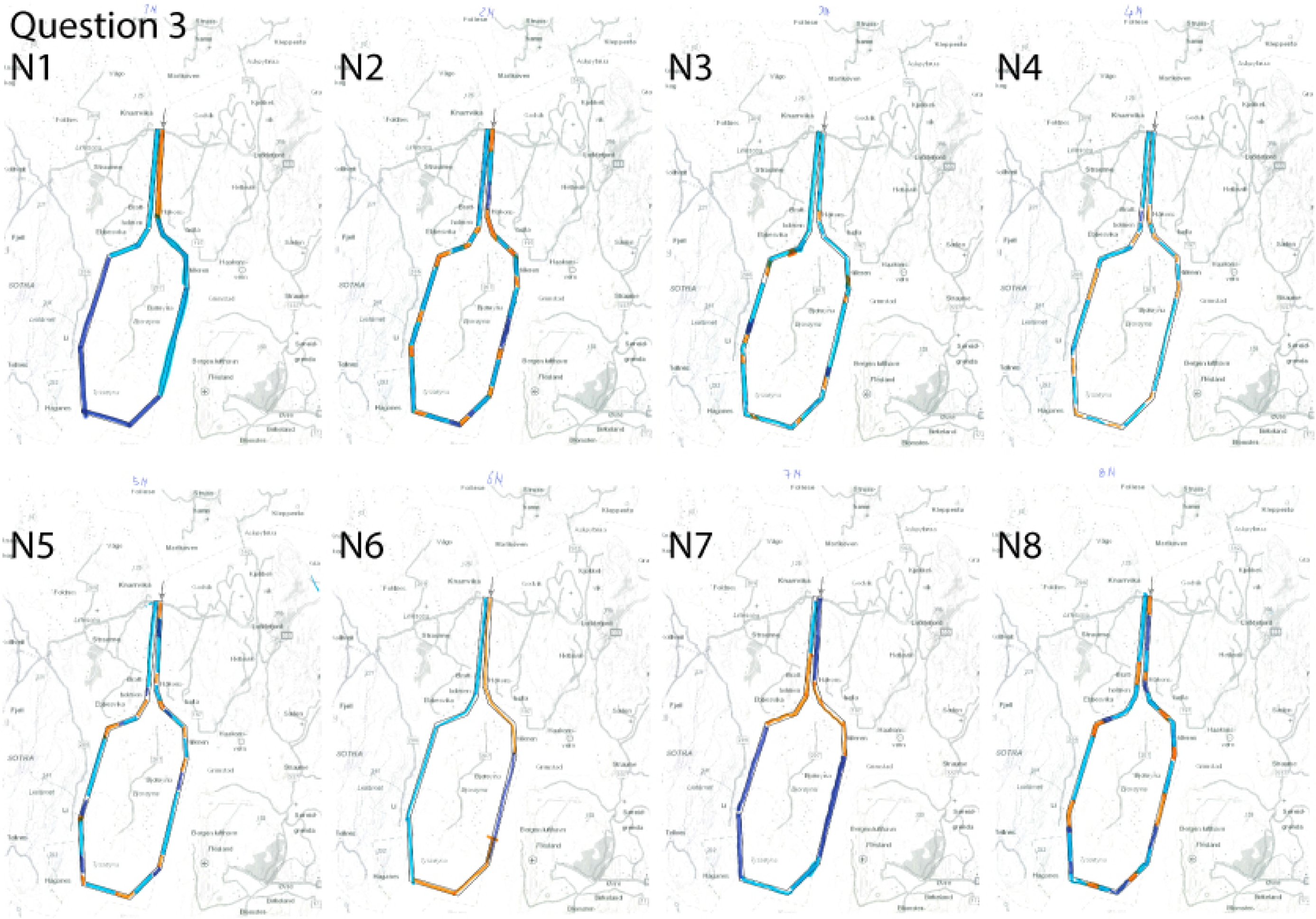


Navigator

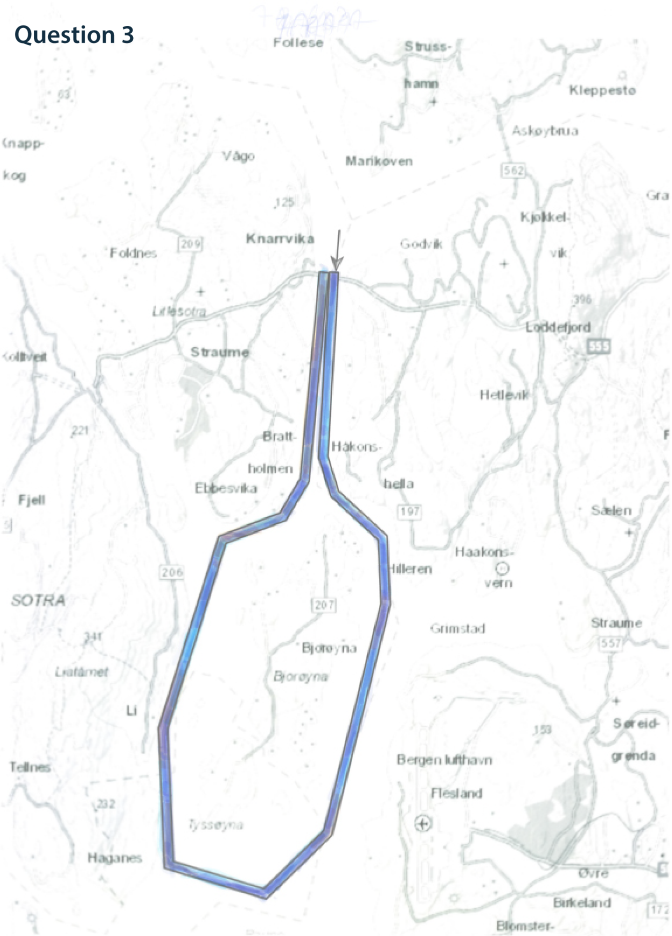
Question 3



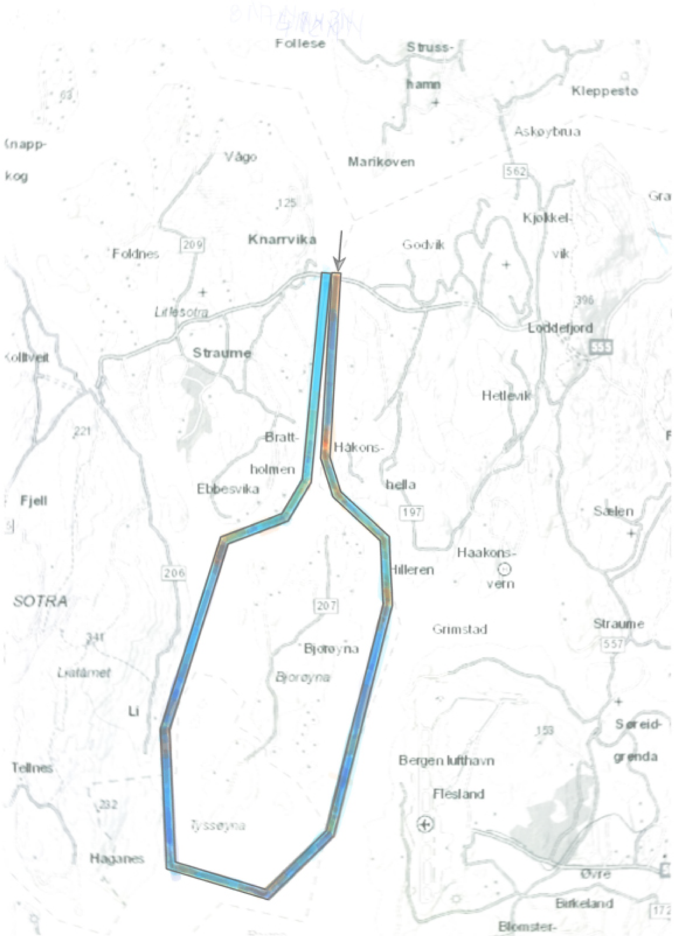
Question 3



Question 3

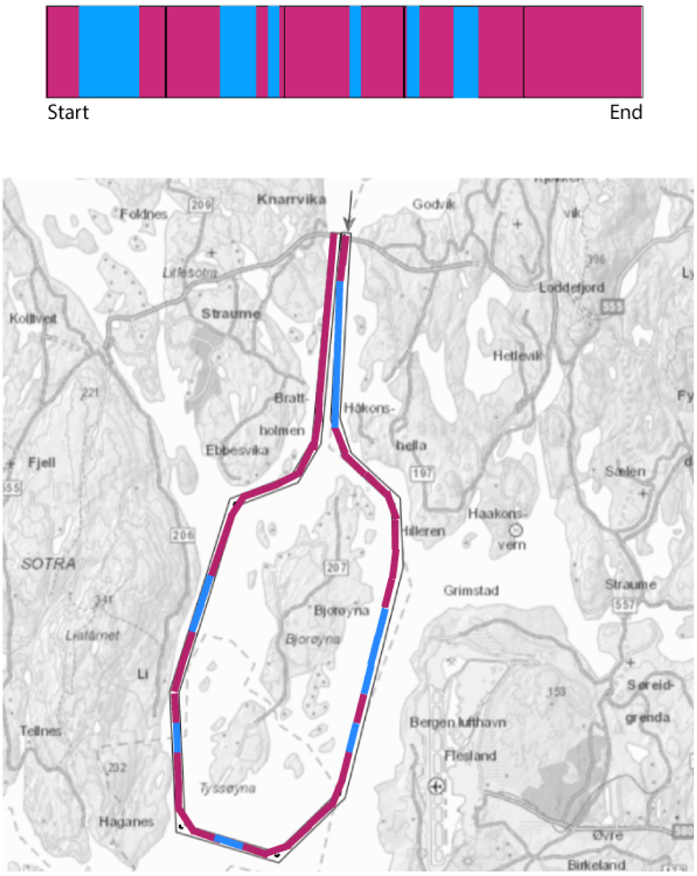


Assistant

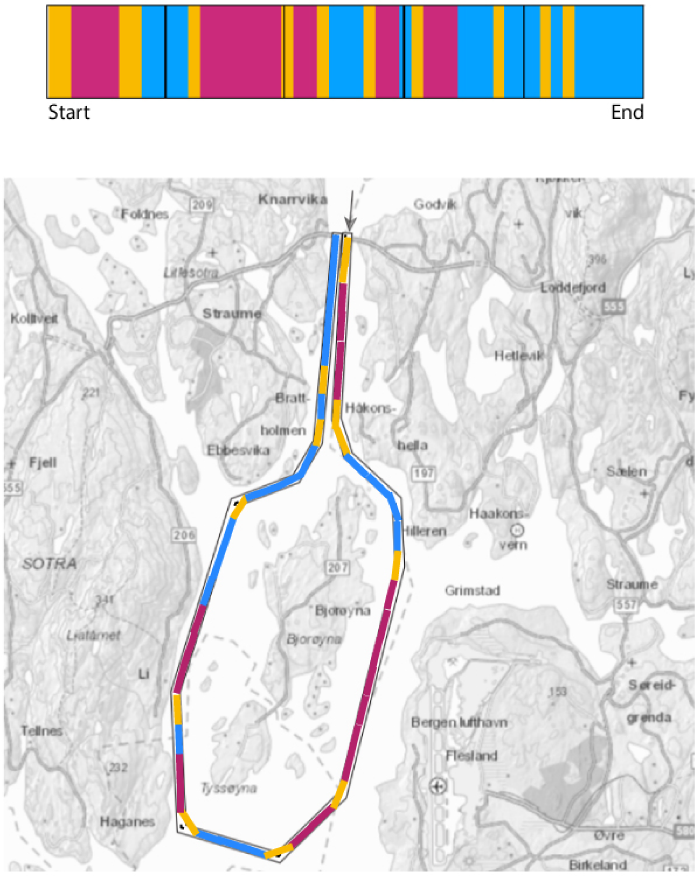


Navigator

Question 3



Assistant



Navigator

A.14 Questionnaire: Table and Graphs

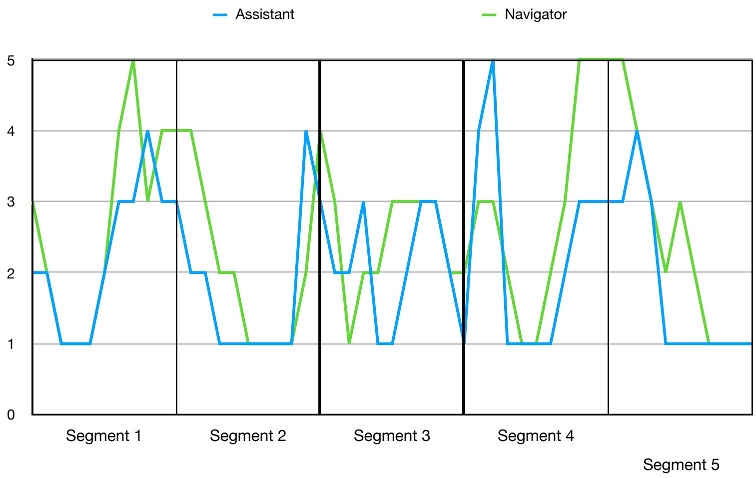
This diagram is in high resolution PDF format - to look closer zoom in.

Assistant	Navigator
2	3
2	2
1	1
1	1
1	1
2	2
3	4
3	5
4	3
3	4
3	4
2	4
2	3
1	2
1	2
1	1
1	1
1	1
1	1
4	2
3	4
2	3
2	1
3	2
1	2
1	3
2	3
3	3
3	3
2	2
1	2
4	3
5	3
1	2
1	1
1	1
1	2
2	3
3	5
3	5
3	5
3	5
4	4
3	3
1	2
1	3
1	2
1	1
1	1
1	1
1	1
2,02	**2,51**

often

sporadically

not required



Average Q2

	Assistant	Navigator
Segment 1	2,27	2,73
Segment 2	1,70	2,10
Segment 3	2,00	2,40
Segment 4	2,40	3,00
Segment 5	1,70	2,30
	2,01	**2,51**

1 - 2 - 3 - 4 - 5
bl lila or

Question 3

Assistant	Navigator
2	3
2	3
1	2
1	2
1	2
1	2
1	3
2	3
2	1
2	1
2	1
2	1
2	3
2	2
1	2
1	2
1	2
2	2
1	2
2	2
2	3
2	2
2	2
2	3
2	1
1	1
2	1
2	3
2	2
2	2
1	1
2	3
2	2
2	2
1	2
1	1
2	1
2	1
2	3
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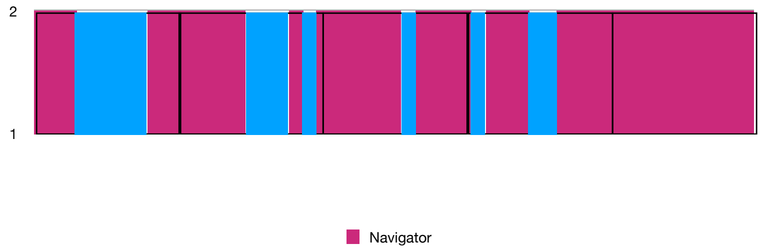
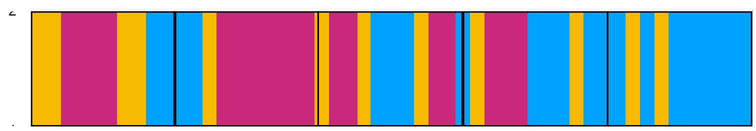
2	1
2	1
2	1
2	1





NTNU

Norwegian University of
Science and Technology