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Remote Piloting in an Intelligent Fairway

A Paradigm for Future Pilotage

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ABSTRACT

Maritime piloting, the process of navigating ships safely in congested waters, is an area where emerging technologies may be used to develop and implement more robust navigation safety systems. This is supported by the commercial potential of remote piloting as a substitute for pilotage exemptions today granted to experienced captains. This paper introduces a novel configuration of remote piloting operations in intelligent fairways. Results are supported by methodological and empirical research with the aim of enhancing our understanding of merging the role of a pilot in autonomous fairway infrastructures. It is demonstrated that under controlled conditions, remote piloting may be a safe option in fairways. However, upscaling remote piloting requires a greater understanding of the risks associated with the implementation of emerging technologies as well as a better understanding of fairway features and environmental phenomena.

Key words: Ship safety, Maritime operations, Remote pilotage, Situation awareness, Intelligent fairways, Maritime simulation.

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1. Introduction

Maritime piloting covers the safety-critical leg of vessel operations in congested routes where the risks for collision and grounding are at their highest (Sandhåland, 2015; Betz, 2015; Lappalainen, et al., 2014; Lahtinen, 2019). Today, the safety of this high-risk part of voyage operations is enhanced by pilots with local expertise (Wild, 2011; Lappalainen, et al., 2014; Lahtinen, 2019). In recent years, growth in maritime traffic density, vessel sizes, and pilot workload has led to the need to improve safety in maritime operations (Betz, 2015; van Westrenen, 1999). Remote piloting has the potential to improve safety, as it eliminates human factors from onboard pilotage operations and may also offer significant cost savings. The latter is topical from a business perspective, especially considering that the remote pilotage has a potential of 55-60% reduction to direct costs of maritime piloting (Danish Maritime Authority, 2014).

The transition from conventional to remote pilotage among stakeholders demands a clear understanding of the role of emerging technologies and risks in relation to the practicalities of remote pilotage (Betz, 2015; Bruno & Lutzhoft, 2009; Hadley & Pourzanjani, 2003). Regardless of growing pressure to lower piloting costs and increase safety, research to date has not determined a paradigm for remote piloting (Bruno & Lutzhoft, 2009; van Westrenen, 1999; Hadley & Pourzanjani, 2003). This is a key deficiency, especially considering that the goal of successful pilotage in remote or conventional applications is aligned with the duty of the pilot to safely guide a vessel to and from her berth by avoiding collision and grounding, among other dangers.

Most of the current research on piloting pays particular attention to challenges associated with situation awareness experienced by the actors involved in such maritime operations (Grech, et al., 2002; Brooks, et al., 2016). The transformation from conventional to remote piloting would require the improvement of timely communication between the crew of a piloted vessel with VTS (vessel traffic service) and the pilots ashore (Bruno & Lutzhoft, 2009; Hadley & Pourzanjani, 1999; ISPO, 2015). Thus, situation awareness should be supported by the fairway infrastructure by sharing navigational information in real time (Lahtinen, 2019). Advanced aids to navigation may contribute to increasing safety standards. However, there is a lack of studies with a focus on fairway infrastructures. Risk management of remote piloting demands understanding the impact of operational practices in both moderate and extreme environmental conditions. Therefore, any future remote pilotage operational framework should account for threshold values for the safe commencement of remote piloting.

Introduction of a novel configuration of remote piloting operations in intelligent fairways demands a holistic understanding of factors influencing piloting. Contributors to remote pilotage operation are determined through an array of surveys, expert interviews, and simulation tests. Following a brief introduction, Section 2 presents a literature survey. Section 3 introduces research methods followed by results from an online survey and interviews. Section 4 presents remote piloting simulator tests that suggest how remote piloting in an intelligent fairway should be practically arranged. Finally, key conclusions are presented in section 5.

2. Literature survey

The literature review presented in this section initially focuses on identifying the key risks of conventional piloting and then provides insight into the safety statistics of prevailing piloting practices. This is followed by a review of papers with focus on the importance of situation awareness and associated communications to highlight the potential of remote pilotage in intelligent fairway operations.

2.1 Piloting

Research on maritime piloting has been limited to the organizational and regulatory perspective, excluding practicalities related to the actual piloting event on board. Limited studies have been conducted on issues such as the effective use of a passage plan. Correspondingly there is a paucity of research providing a holistic overview of the piloting process (Lappalainen, et al., 2014). This is due to the extensive regulatory framework governing the organizational arrangements of piloting. The International Maritime Organization's (IMO) first definition of pilotage service arrangements date back to 1968 (IMCO, 1968). More recent IMO resolutions provided a framework for the operational (IMO, 2003) and organizational (IMCO, 1968) arrangements of piloting. This regulatory framework focuses heavily on pilot transferring arrangements (IMO, 2011) and the safety of pilot boarding arrangements (IMO, 2012). These principles are reflected in the International Standard for Maritime Pilot Organizations (ISPO, 2015). From the vessel crew point of view, relevant documentation includes the International Convention on Standards of Training, Certification and Watch-keeping for Seafarers (IMO, 2017) and the International Bridge Procedures Guide (ICS, 2016).

2.2 Key risks in conventional pilotage operations

Piloting today is not a fault-free solution. This statement is supported by the International Group of P&I Clubs, which reported 260 claims due to pilot errors valued at over USD 100,000 between February 20, 1999 and 2004 (International Group of P&I Clubs, 2004). This conclusion is particularly alarming considering that although the total of all cargo transported by sea increased by 42% from January 2000 until December 2016, physical fairways have not changed (UNCTAD, 2017). The Finnish government has reacted to this statistic in two ways: (a) the Finnish Transport Agency designated selected fairways along the Finnish coast as test platforms for the development of infrastructure intelligence; (b) an amendment to the Finnish Pilotage Act came into force in early 2019, enabling remote piloting tests in specified fairways (Ministry of Transport and Communications, Finland, 2019). Lahtinen et al. (2019), Betz (2015) and van Westrenen (1999) describe pragmatic safety improvements that could be possible via the introduction of a revised Pilotage Act. Those are supported by a review of the following safety records:

- Between January 2006 and February 2007, four maritime pilots passed away in the USA as a result of falling from pilot ladders while embarking or disembarking from a vessel. A fifth victim, a pilot boat operator, died when a pilot boat capsized after a pilot's transfer (Professional Mariner, 2007).
- A similar pilot boat accident occurred in Finland on December 8, 2017, when two pilot boat operators died after their boat lost stability and capsized shortly after transfer of the pilot on board (Safety Investigation Authority, Finland, 2018).
- Embarkment was found to be the second most dangerous part of pilot work in a study that included maritime pilots in New Zealand and Australia in 2006. In the same study, unsafe embarkation arrangements were classified as the sixth most dangerous risk (Darbra, et al., 2006).
- The waiting time involved in pilotage operations poses significant risks to vessels. One relevant case is the pilotage accident that befell M/V New Carissa, which was in-bound for Port of Goos Bay in Oregon, US (Oregon Department of State Lands, 2009). Due to harsh weather conditions, the pilot was delayed. The captain decided to set at anchor two nautical miles off the coast. Overnight, the vessel dragged her anchor. This resulted in grounding and finally the breaking of the vessel hull in two.

From these findings, it may be concluded that safe boarding arrangements for pilots have not evolved in step with the increase in traffic density. Consequently, IMPA conducted a survey in 2017 to examine pilot embarkment safety. Results indicated that 16% of the internationally inspected pilot boarding arrangements contributed to potential safety risks (IMPA, 2017). It is thus evident that any efforts to remove embarkment from piloting may increase overall safety standards.

2.3 Safety statistics of conventional pilotage

The safety records of Finnish fairways, based on reviews of incident and accident reports from Traficom (Finnish Transport and Communication Agency) and Finnish West Coast VTS (see Figures 1, 2), are presented by Lahtinen et al. (2019). According to this study, 11,935 vessels visited the Port of Rauma between 2009 and 2019. Traficom statistics for this period (Figure 1) showed that ship grounding, collision and capsizing were the main types of accidents. Interestingly, of the five cases of grounding, four occurred with a pilot on board and one under the command of a certified vessel master with pilotage exemption. Of the four reported groundings, two resulted from human errors and another two from a technical failure. The pilot-exempted vessel under the command of a certified master experienced one case of grounding, reportedly due to human error. Between 2014 and 2019, 5,592 vessels visited the Port of Rauma (see Figure 2). Reported incidents over this period were categorized as involving shallow water, technical failure, communication, collision danger and exit from the fairway area. Under all modes of operation, robust and timely communication is vital for the successful management of operational risks. In Figure 2, shallow water danger is presented as the most frequent scenario. The research of Lahtinen et al. suggests that cases where VTS communicated a shallow-water warning were linked to communication failures. Moreover, Lahtinen et al. concluded that VTS does not provide standardized decision-making support for vessel crews, leaving situational discretion in a potentially dangerous situation to the individual VTS operator.

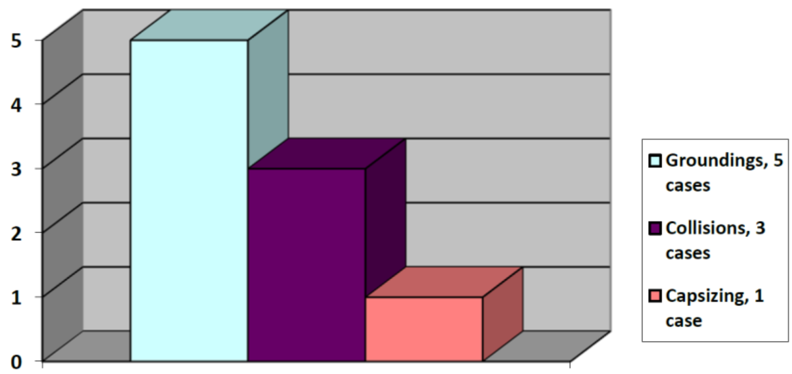

Figure 1. Accidents in Rauma fairways 2009-2019 reported by Traficom (Lahtinen, 2019)

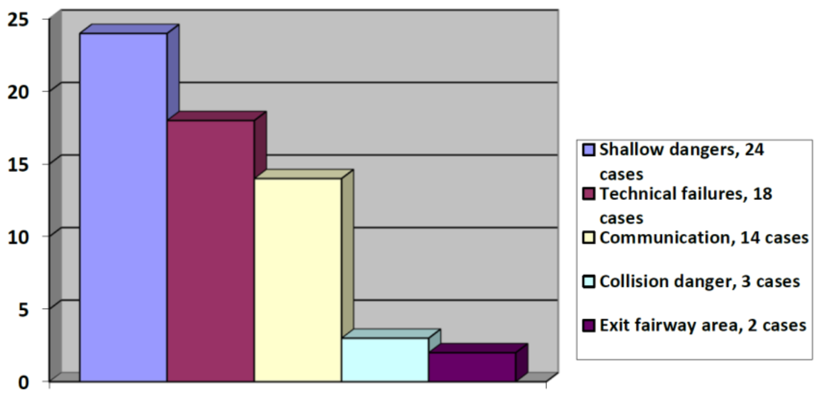

Figure 2. Non-conformities in Rauma fairways 2014-2019 reported by West Coast VTS (Lahtinen, 2019)

2.4 Remote piloting

Early efforts to remotely pilot vessels date to the early 1960s. Those were based on inaccurate radar images supported by VHF radio communication (Betz, 2015; Hadley & Pourzanjani, 1999). To date, the most advanced practical efforts to establish remote piloting are limited to part of the fairway, largely relying on the same functional principle as early applications. One example of this is the Port of Rotterdam, where SBP (Shore Based Pilotage) is provided between the pilot station Maas Center and off the Hoek van Holland Traffic Center. In this port the pilot communicates verbally with the piloted vessel through a VTS-monitored VHF channel, supported by a VTS monitoring view and shore-based radar image (Port of Rotterdam, 2019). Therefore, it is evident that maritime piloting has the potential to enhance safety by means of the efficient utilization of available technology (Betz, 2015; Brooks, et al., 2016). In recent years, the development of maritime piloting has mainly focused on applications of shore-based piloting (Bruno & Lutzhoft, 2009; Hadley & Pourzanjani, 1999). This is done to remotely guide vessels to safer waters and enable the pilot to safely embark the vessel for the remaining passage and entry to port.

Today, there is evidently a consensus among regulating bodies on how conventional piloting must be conducted, and there appears to be a mutual understanding of the limited applications of remote pilotage. However, the absence of a clear structural and operational definition casts a shadow over the widespread use of remote piloting. According to ISPO, remote pilotage is defined as *"an act of pilotage carried out in a designated area by a pilot licensed for that area from a position other than on board the vessel concerned to conduct the safe navigation of that vessel"* (ISPO, 2015). This statement does not exclude or demand the physical presence of a pilot on board. Interestingly, ISPO also defines shore-based pilotage as *"the means to assist a vessel in proceeding to/from an alternative boarding position."* This statement actively limits the coverage of the remote piloted part of the passage. This antipathy towards the possibility to pilot a vessel from locations other than on board has been present for as long as discussion of remote piloting has been ongoing (Betz, 2015; Hadley & Pourzanjani, 2003). Hadley & Pourzanjani further describe that resistance has been based on skepticism about the capabilities of technology, vessel, and crew.

Summarizing the above indicates the presence of a control problem of complex systems associated with remote piloting, as discussed by Bruno & Lutzhoft (2009). Moreover, jaundiced views usher the selection of vessels and crews suitable for being piloted remotely instead of aiming to remotely pilot all vessels (Hadley & Pourzanjani, 2003; Bruno & Lutzhoft, 2009). Bruno & Lutzhoft present remote piloting as a control problem, in the sense of maintaining the ability to control a complex system. According to the authors, this problem could be handled by setting the preconditions for safe remote pilotage operations. Such preconditions should be suitable for each vessel type and size, training of vessel crew, feedback to pilot and finally standardized procedures and communication routines. However, their study excludes situation awareness and the role of the fairway infrastructure as an enabler of vessel control.

2.5 Situation awareness

Traditionally, situation awareness in navigational bridge management has been supported by the view that bridge ergonomics should support the use of windows and radar imaging to enable excellent visibility under any weather conditions. Visual feedback gained from vessel surroundings is paramount for successful pilotage (van Westrenen, 1999). However, on-site visual, auditory and physical impressions of the vessel cannot be transferred ashore. A recent collision accident between the tanker vessel Sola TS and the Norwegian navy frigate KNM Helge Ingstad illustrates the value of on-site perceptions (Lahtinen, 2019). A review of this accident clearly demonstrates that placing the pilot with a holistic situation overview ashore may increase operational safety margins (Lahtinen, 2019). Yet, it may not be necessary to fully replicate the visual perception and feel of the vessel.

2.6 Communication

According to Endsley, *"It is not enough if a single operator in the situation possesses situational awareness. However, if information is not successfully transmitted to another team member who needs it, this may result in a critical error"* (Endsley, 2015). This means that communication is at the heart of successful decision making and the composition of situational awareness. According to Lahtinen et al., *"Safe remote piloting assumes seamless interaction within a complex environment that encompasses linear and non-linear communications between people, processes and technologies"* (Lahtinen, 2019). These interactions manifest as communication loops consisting of voice communication and data transfer, which potentially affect human behavior during ship operations.

A suggestion for lowering the risk involved in remote piloting was provided by Bruno & Lutzhoft (2009), who discussed the significance of standardized communication phrases between vessel crew and shore-based assistance. This conclusion is further supported by the positive experiences on the use of standardized communication from aviation (Betz, 2015; van Erve & Bonnor, 2006). However, the complexity and diversity of the piloted fairways pose challenges for defining standard vocabulary and phrases (van Erve & Bonnor, 2006), which should be compliant with E-navigation standards (IMO, 2019) and associated regulatory reporting schemes (IMO, 2002).

2.7 Intelligent fairway

The integration of remote piloting and intelligent fairway could result in the reduction of human errors. However, it is generally understood, that remote application merely moves a pilot to another location. Thus, the remote application keeps humans in the loop and the risks will simply migrate elsewhere (Lahtinen, 2019).

There is a limited amount of research on navigational risks in fairways. For this reason, in 2016 IALA facilitated an e-fairway project that involved enhanced AIS (Automatic Identification System) safety message distribution, which was of limited relevance to intelligent fairway development efforts (IALA, 2016). More recently, they established in Finland an e-navigation testbed simulating the Rauma 12-meter fairway (IALA, 2018). In this testbed, intelligent fairway development is conducted as part of the ISTLAB project, collecting robust navigation and environmental data from the fairway and vessel for the use of a remote pilot. Initially, this data consists of a virtual GPS base station network for position accuracy and reliability, S-102 bathymetric model for real-time under keel clearance (UKC), weather and sea state information, camera views from the fairway and remote pilot access to the VTS display (SAMK, 2020).

Taken together, previous studies suggest that remote piloting is a control problem (Bruno & Lutzhoft, 2009), a technical challenge reflecting the reluctance to change something that already works (Betz, 2015; Hadley & Pourzanjani, 2003) and hence a cultural challenge (Wild, 2011) or a management of a change issue as defined by Bruno, Coltman & Yang (2016).

2.8 Commercial aspects

Growing maritime traffic density and vessel size implies the need to improve safety in maritime operations (Bruno & Lutzhoft, 2009). However, commercial pressure to reduce the costs of piloting and accordingly improve the efficiency of pilotage operations ushers in an urgent need to introduce remote piloting in practice (Hadley & Pourzanjani, 2003). The potential of remote pilotage systems to reduce health and safety risks (Betz, 2015) is supported by avoiding embarkation and disembarkation to and from a vessel in rough weather conditions. Remote piloting also offers the potential for significant cost reduction when pilot cutters and or pilot stations in remote locations no longer would be necessary and pilot use of working time would be more efficiently channeled for piloting (Brooks, et al., 2016; Danish Maritime Authority, 2014). Furthermore, pilotage exemption certificates for experienced captains could be replaced with remote pilotage service, freeing the vessel company from costs related to pilot exemption certification while providing a source of income to the piloting company. Taken together, previous studies suggest that remote pilotage could contribute to safety and financial sustainability of the pilotage operation.

3. Methods and key results

To better understand merging the role of a pilot in operations involving autonomous fairway infrastructures, we followed a methodology comprising an empirical survey, management interviews and finally a series of tests in a simulated environment. The operational transformation required to enable remote piloting includes changes in the work descriptions of various actors, and the technology on board and in the fairway is also subject to change. This suggests a synthesis of multiple research methods for supporting a holistic overview of the subject under this study (Brady, 2015).

In research practice, qualitative research approaches are frequently used in combination with quantitative and mixed methods (Miles & Huberman, 1994). This is because such a combination supports gaining a holistic overview. Along these lines, for the online survey presented in this paper, use of an expert group along the Delphi- technique was preferred, as it combines quantitative and qualitative data collection (Brady, 2015). The online survey produced empirical data that supports the development of remote piloting in two steps. Step 1 focused on understanding shortcomings in current operational and organizational piloting practices. Step 2 elicited expert opinions from actively serving pilots to define the roles of different stakeholders in remote piloting environments.

Interviews were conducted on a one-on-one basis with representatives from a Finnish pilotage provider, Finnpilot Ltd, and Finnish VTS management after the completion and initial assessment of the online survey results. Expert answers provided qualitative information and helped realize the impact on organizational transformation when moving from conventional to remote piloting. The online survey and expert interviews indicated non-conformities between a pilot's regulatory role and the operational reality today. Simulation tests were carried out to minimize uncertainties regarding the roles of different stakeholders in remote piloting. These tests helped to determine the safety and feasibility of remote pilotage under preset environmental conditions.

3.1 Online survey

Online survey questions were distributed into three groups, namely (1) pilot-crew-VTS relationship; (2) piloted vessel crew abilities and (3) pilot use of data. Group (1) helped to better understand the relationships of stakeholders involved in conventional piloting. This information is particularly interesting, as it is generally known that the prevailing piloting practice is in no way fault free. Therefore, understanding faults is useful in avoiding inadvertently transferring unwanted practices to remote piloting practice. Group (2) helped understand how vessel crews work with pilots in fairway navigation. This information helped identify possible anomalies between a pilot's regulatory role and the operational realities he/she faces while on board. Group (3) helped to prioritize the key information pilots should have in hand for decision making.

An expert interview group was set up to formulate the survey questions. This group consisted of five experienced practitioners from the fields of social psychology, piloting, maritime safety, and navigation. A bank of questions that reveal the relevant views of the target group members was created. Then an initial bank of survey questions was formed as a tabletop exercise and sent directly to expert group members for evaluation. After modifications, the expert group reassessed the questionnaire before sharing it with the target group. The target group for the survey consisted of actively serving marine pilots from Finland, Sweden, Norway, Denmark, Estonia, and the United States. The number of received answers proportional to the number of all pilots that received the survey were: Finland 35/150, Sweden 29/210, Norway 47/290, Denmark 25/170, Estonia 6/43, and United States North East Pilotage district 6/10. The data collection method allowed for flexible participation via a link to an online survey shared through national piloting authorities.

The survey had 19 questions, of which 16 were numerical slide bar answers divided into four research areas, namely: (a) pilot-crew relationship, (b) vessel crew abilities, (c) pilot use of data, and (d) pilot decision making. The contents of the survey were scattered so that questions belonging to a single research area would not appear in sequence. Additionally, three questions with written free answers were interpreted through keywords and key expressions. In turn, the answers revealed multiple gaps in current piloting procedures and perceptions of remote piloting. The survey questions were submitted as statements that the respondents were asked to agree or disagree with on a scale of 1 (totally disagree) to 10 (totally agree). The written responses to the online survey presented below are divided into ten categories representing clustered statements. The remaining written answers were disregarded as irrelevant or highly ambiguous.

3.1.1 The pilot-crew-VTS relationship

The Pilotage Act (2003) states that: *''The pilot shall supervise any measures related to the steering and handling of the ship that is of significance for the safety of vessel traffic.''* Thus, the regulatory role of a pilot is to act as a local expert and supervisor of crew actions. However, the survey results clearly indicated that a pilot's role resides in robust decision making rather than in supervising crew decisions. Table 1 presents answers related to the pilot-crew-VTS relationship. Of the 148 pilots who completed the questionnaire, 89% indicated that trust between the pilot and the vessel crew is one of the most important factors for successful pilotage. Of all respondents, 78% reported having an active advisor role rather than supporting crew decisions. In response to the statement, *"Vessel crew is aware of pilot role and responsibility as part of the bridge team,"* 69% of pilots agreed. Still, only 59% of pilots felt that master-pilot information exchange was completed in full. Opinions on the role and relevance of VTS in conventional piloting were evenly distributed (see Table 1).

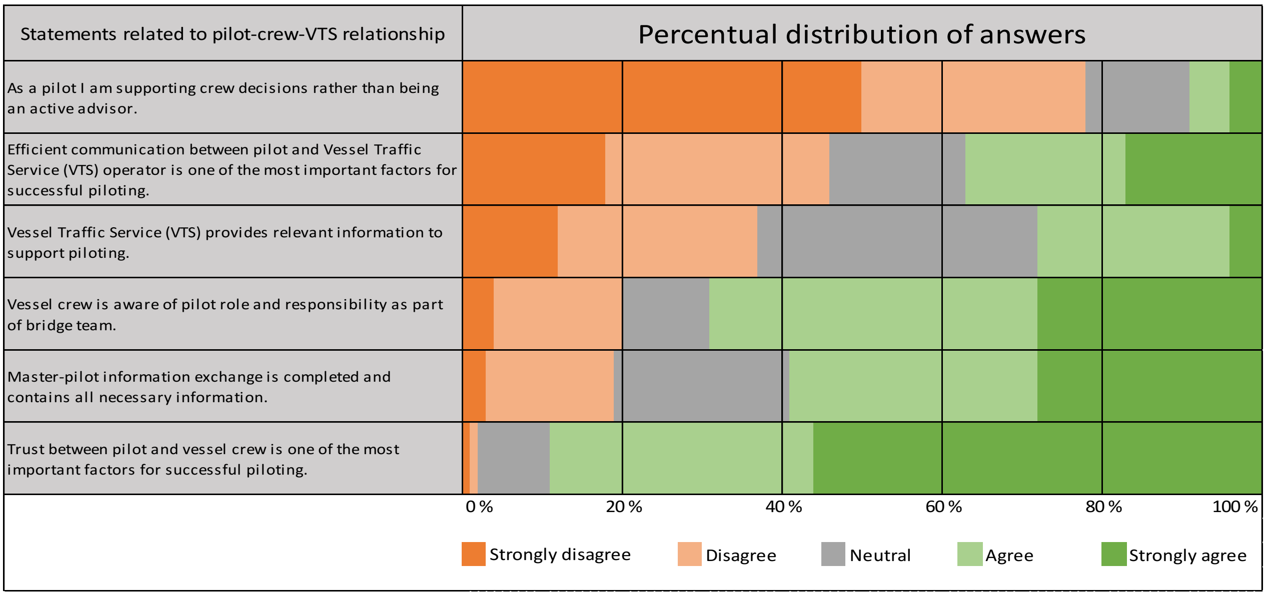

Table 1. Survey answers concerning the relationship between vessel crew, pilot and VTS.

3.1.2 The management of vessel crew capabilities

Table 2 demonstrates how controversial an operational reality can be when compared against the regulatory framework. Of the pilots, 64% disagreed with the statement: *"A Vessel crew is familiar with monitored radio channels and local reporting obligations."* This view was further supported by the 48% disagreement with the statement, *"Vessel crew communicates well in English and by* *using the IMO Standard Maritime Communications Phrases (SMCP) as appropriate."* Consequently, 97% of pilots reported that the crew expects the pilot to handle all external communications during pilotage, and 72% of pilots reported that vessel crews expect the pilot to also be responsible for vessel steering. Finally, 48% of pilots reported that vessel crews are incapable of maneuvering vessels safely on their own.

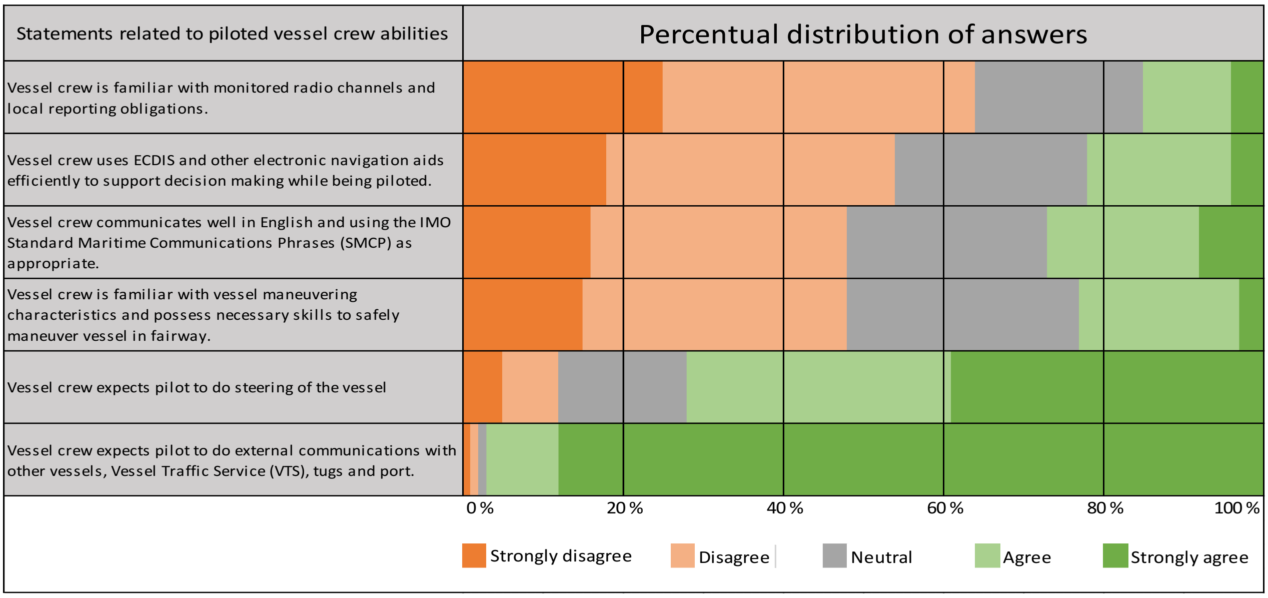

Table 2. Survey answers concerning piloted vessel crew abilities.

3.1.3 Pilot use of data

The pilot preferences on the use of data in support of navigation decision making are presented in Table 3 and can be summarized as follows:

- 65% of those who responded prioritized pilot carry-on equipment, the Portable Piloting Unit (PPU), over the vessel Electronic Chart Display and Information System (ECDIS). Although navigation data records presented in PPU are similar to those of ECDIS, the former has an in-built accelerometer for heel and trim angle representation. PPU, therefore, has the potential to assist pilots in the evaluation of squat effects in extreme under keel clearance situations.
- 72% of those who responded felt that enhancement of the Global Positioning System (GPS) may help to improve safety.
- The importance of access to good quality weather data in the harbor and the fairway areas was acknowledged by 73% and 82% of pilots, respectively.

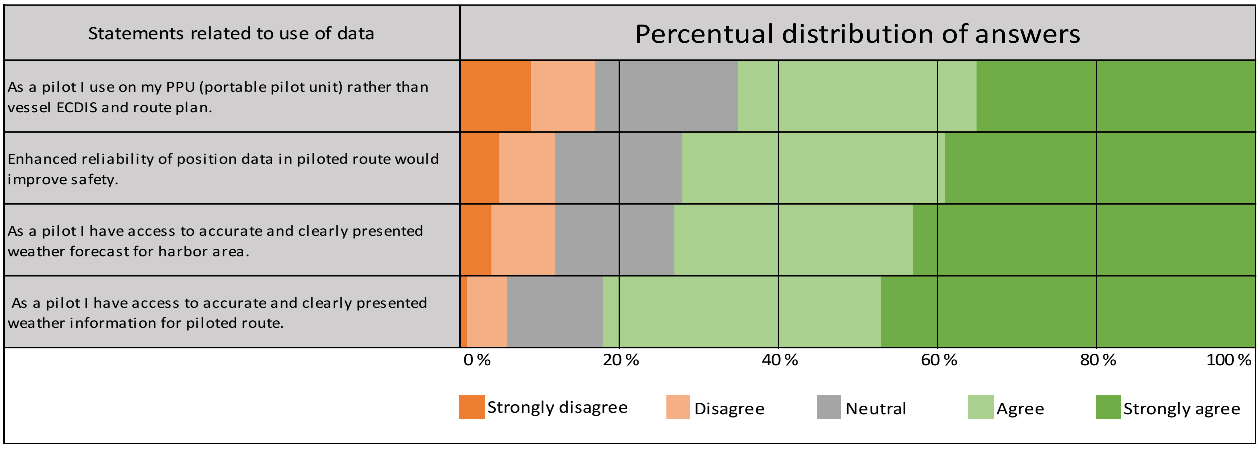

Table 3. Survey answers concerning pilots' use of data.

3.1.4 Factors for successful piloting

One respondent answered the question, *"Describe briefly the key factors for successful piloting"* as follows: *"Communication onboard between the bridge team and pilot, situation awareness, knowledge in vessel maneuvering characteristics, bridge team interests in navigation during pilotage,"* highlighting communication. Of all responding pilots, 56 acknowledged communication as a key factor for successful piloting (see Table 4). The term situation awareness as a success factor attracted only 20 respondents. This could be attributed to the respondents connecting situation awareness and communication.

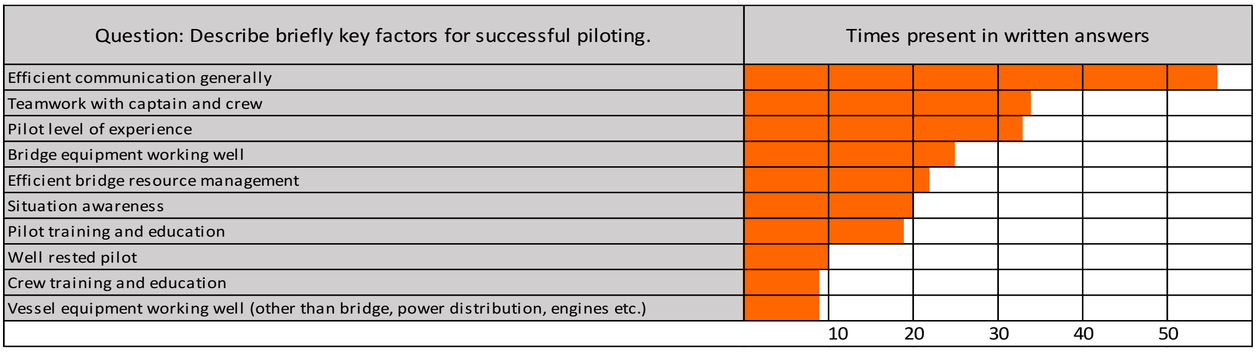

Table 4. Written survey answers concerning factors for successful piloting.

3.1.5 Factors to facilitate remote piloting

Although 28 out of 148 pilots responded that remote piloting is not possible, written responses to the question "*describe briefly the most important factors to facilitate remote piloting*" revealed the following views:

- *"Crew competence and ability to communicate is the most important factor for successful piloting"* (see Tables 4, 5).

- *"Lowering the necessity to communicate between pilot and crew through advanced technology is key for remote pilotage"* (see Tables 4, 5).

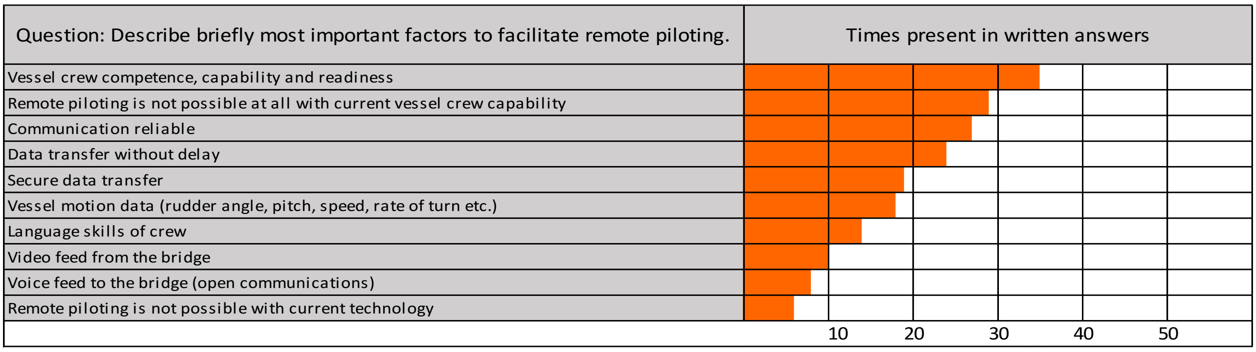

Table 5. Written survey answers concerning facilitation of remote piloting.

3.1.6 Key areas of improvement for safety management

Table 6 gives an overview of organizational problems pilots experience today. Written responses to the question "*describe briefly areas of improvement for safety management in your organization*" revealed shortcomings in the current organizational framework supporting piloting. Notably, 20 answers to this question were left blank and four responders declared that they did not understand the question. Seven answers were irrelevant and thus disregarded. The results can be summarized as follows:

- *"Piloting organizations lack efficient internal communication."* This statement is supported by 56 of the 148 pilots who prioritized communication (see Table 4). That said, 27 of the 148 pilots questioned the effectiveness of reporting systems and internal communication within piloting organizations (see Table 6).
- *"Piloting management has receded from operational reality"* (see Table 6). This statement was supported by a minority of 11 out of 148 pilots. Although the sample supporting this opinion was small, organizational communication may be recognized as an issue.
- *"The role of safety management systems has faded among pilots"* (see Table 6). A large number of invalid responses express pilots' extrinsic views concerning the significance of safety management. This is consistent with the views that solely focus on the relationship between the pilot and the vessel (see Tables 4, 5). Only seven pilots expressed the view that the lack of guidelines and operational procedures may be the main reason behind faults in pilotage operations.

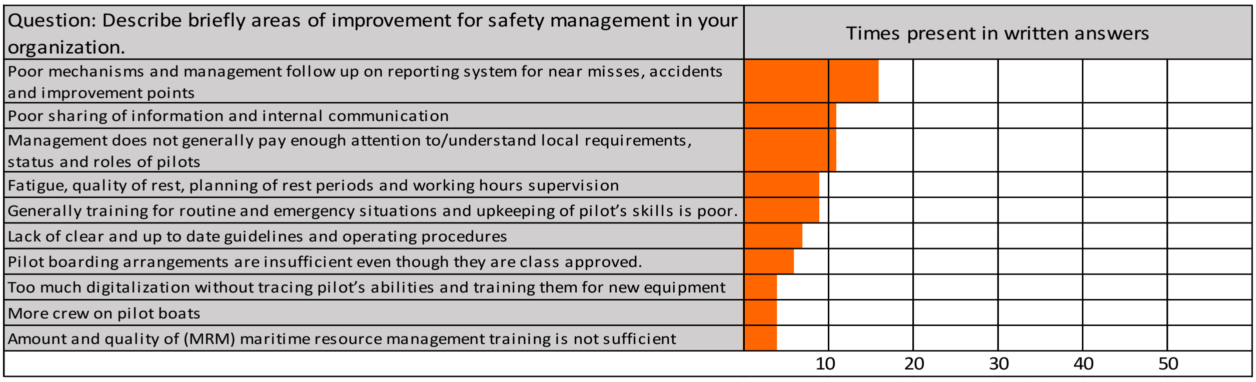

Table 6. Written survey answers concerning piloting safety management.

3.2 Individual expert interviews

The online survey provided valuable information on remote piloting operational aspects. To better understand organizational influences on remote piloting operations, a series of expert interviews that involved staff from VTS Finland and Finnpilot Pilotage Ltd. were conducted. From Finnpilot Pilotage Ltd. the pilotage director and technology manager were interviewed separately. After this, from VTS Finland, the senior specialist of VTS services was interviewed. As piloting is a process extensively defined by the pilots themselves, the questions were generic, and the interview approach was informal and unstructured. Table 7 summarizes questions and key findings.

Question	Answer
Interview of Finnpilot Pilotage Ltd. management	
Should piloting procedure be more standardized?	Currently there are no prescriptions for pilotage operations (see Table 6). The Pilotage Act leaves room for interpretation and the responsibility for operational definitions lies with the pilotage service providers.
How does the pilot role vary when piloting is done remotely?	Answering this question requires the use of a test bed that complies with the demands set by the Pilotage Act. It must consist of vessel position, rate of turn, propeller pitch, speed, and rudder angle, as a minimum and without latency.

What are the main challenges for remote piloting?	Remote piloting should comply with the order of demands (methods, techniques, and practices) listed in the Pilotage Act. A functional risk management framework is an essential element in maintaining compliance with traffic and environmental regulations. This framework should determine the geographical extent of remote pilotage and the stakeholders with their duties.
Interview with VTS management	
Should pilot-VTS interaction be more standardized?	Standardizing and sharing the same workspace could be a good way forward in terms of enhancing cooperation and sharing knowledge. However, interpersonal characteristics may lead to poor communication between the pilot and VTS operator.
How does the VTS operator role vary when piloting is done remotely?	VTS operators and pilots suffer from outdated understanding of their roles and responsibilities. This casts a shadow of uncertainty over the development of remote piloting.
If piloting would be done remotely, could it be combined with VTS?	Today, navigational assistance is given on demand to piloted or pilot-exempt vessels by the VTS operator via radar network and use of AIS data. This function is strictly advisory and does not release the vessel’s master or pilot from his obligations. Therefore, in the event of navigational assistance, the roles of the VTS operator and remote pilot should be further examined.

Table 7. Interview questions and summarized answers

3.2.1 Pilotage company management interviews

Interviews with the management of Finnpilot Pilotage Ltd. led to the conclusion that it is essential to introduce improved management guidelines and standards for remote piloting. Since piloting is not a fail-safe procedure, the development of remote capabilities calls for recognition of the gaps in current procedures. This view correlates well with the pilots' level of involving VTS in decision making (Table 1) and pilots' distrust of crew abilities (Table 2).

3.2.2 VTS management interviews

Interview with VTS management indicated a demand to further examine the roles and responsibilities of operational stakeholders engaged in remote piloting. VTS management acknowledges that VTS operators have an outdated understanding of their role in navigational decision making. Furthermore, as pilots have individual ways of cooperating with VTS, operators are forced to adopt individual approaches to working with each individual pilot.

3.3 Simulation tests

Simulator tests were conducted in the Satakunta University of Applied Sciences (SAMK) maritime simulator in Rauma, Finland. Testing simulated four pilotage scenarios aiming to determine the safety and feasibility of remote pilotage under preset environmental conditions (see Tables 8, 9). The testbed consisted of the data inputs listed in Table 8, and the duration of each test was approximately 1.5 hours. Four tests were carried out, and test procedures were agreed upon and briefed between all participants before each test. The simulator environment consisted of four segregated navigation bridges separated with sound-insulated walls. One of these bridges acted as the remotely piloted vessel and one as a remote pilot unit. Figure 4 presents the selection of navigational data based on replication of bridge environment and associated observations. Additionally, a weather station information display and four fairway camera views positioned along the fairway were offered for remote pilot in simulation tests.

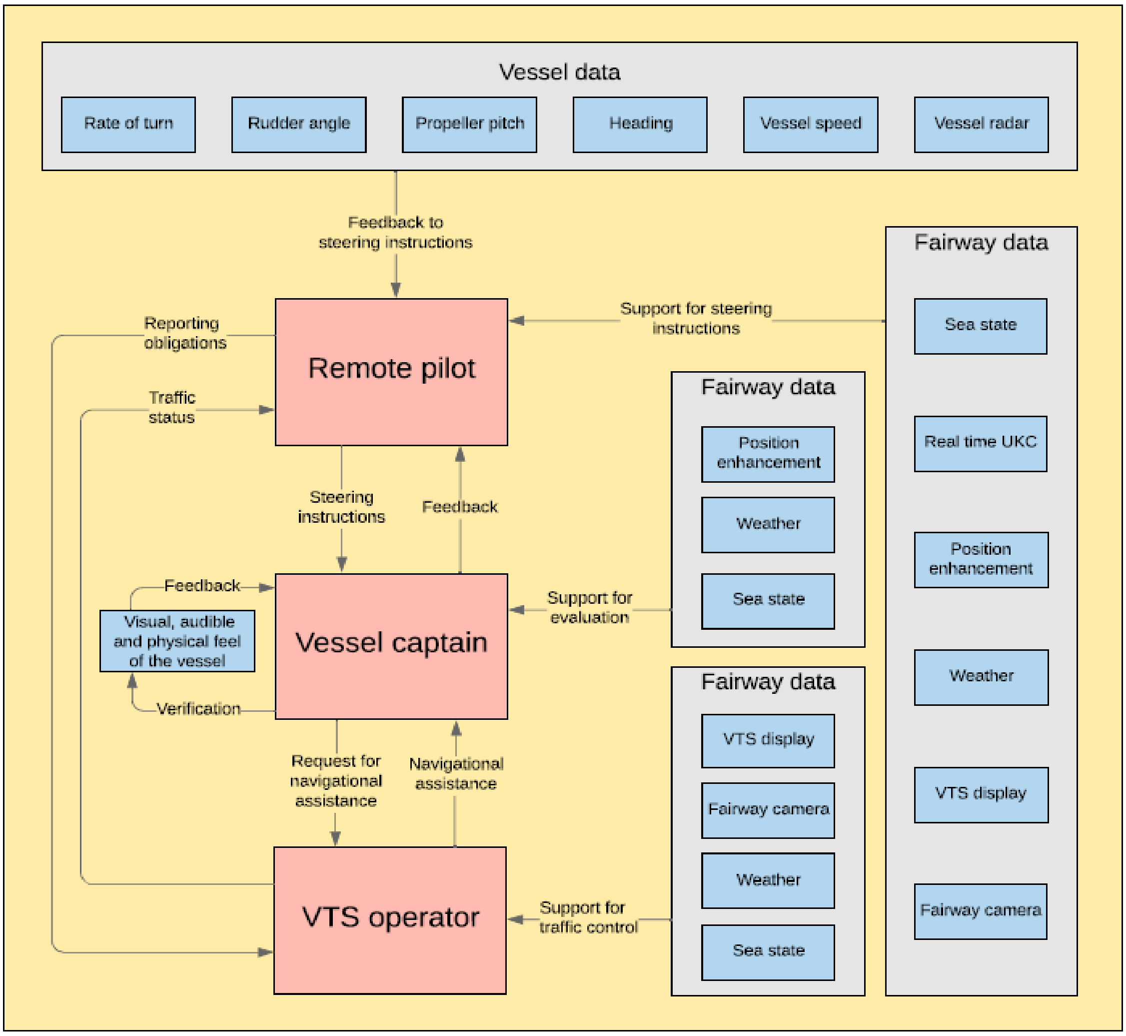

Figure 4. Initial operational configuration of remote piloting with stakeholders and information exchange.

Data originating from the piloted vessel (Table 8) was partially transmitted wirelessly and partially transferred with cabling from the piloted vessel simulation room to that of the remote pilot. Thus, the expression "slave display" is used in Table 8. This arrangement ensured remote pilot access to vessel data without latency. Fairway-originated data listed in Table 8 originated from the simulation software only and, as such, was displayed to the pilot as a direct feed from simulation computing. During simulation tests, pilot observations were recorded. After the associated debriefing, a second test was conducted with no access to the bridge camera. The second test aimed to reveal if remote piloting was possible in the given conditions without visual observation from the navigational bridge, and if so, what source of information was preferred. A third test was conducted without a bridge camera view and vessel radar image, further disconnecting the remote pilot from the piloted vessel data, which meant that the remote pilot only had access to instrumental data. Finally, in the fourth test, the pilot was placed in the same simulation room as the vessel crew, thereby simulating conventional piloting. Configuration of remote piloting and associated information exchange (Figure 4) and environmental conditions were the same in all tests (see Table 9, item 3). In these tests, the VTS operator was facilitated with a VTS display that provided the same information that VTS operators have at their disposal, excluding the VTS radar.

Test equipment and associated available data varied in terms of how they reveal differences in the distribution of pilot observations and assess the gravity of different sources of information for pilot decision making. Eye-tracking equipment was used to collect pilot visual observation data (see Figure 3). Eye-tracking glasses are equipped with four eye movement observing cameras, gyro, and accelerometer, providing data on real-time observations of participants' gaze.

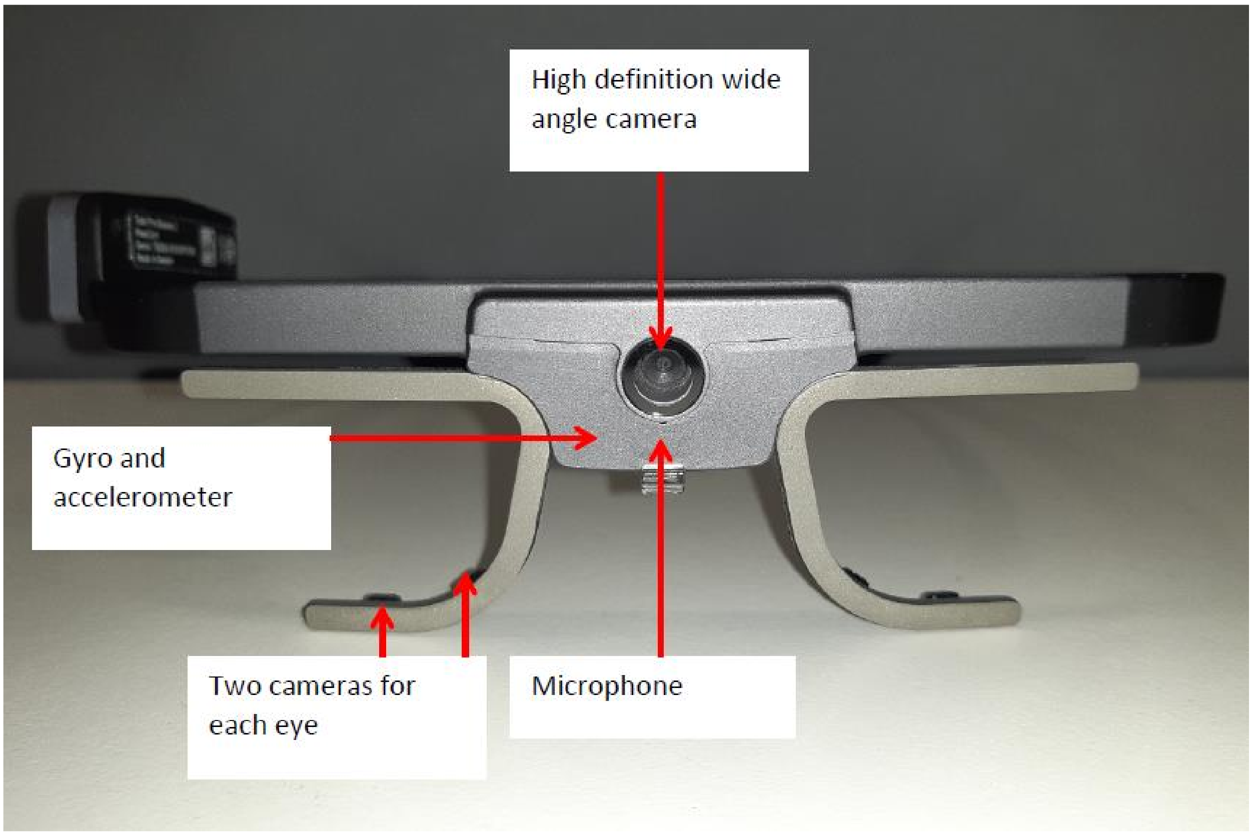

Figure 3. Eye tracking glasses used for data collection in simulation tests

Vessel data	Fairway data
VHF (Very High Frequency) radio for voice communication	four fixed camera views from fairway
remotely inclining and rotational camera view from bridge	enhanced GPS (Global Positioning System) satellite-based position
conning display providing vessel dynamic data (rate of turn, speed, heading, position) in a single display (slave view, replication of vessel display)	VTS traffic monitoring display
RADAR image (slave view, replication of vessel display)	S-102 bathymetric data providing the real-time water column depth of the fairway
rate of turn	weather buoy data providing various environmental conditions (listed below)
speed through water	wind speed and direction from port and fairway
speed over ground	sea state (max and significant) in port and fairway
propeller pitch	tidal streams
rudder angle	sea current in port and fairway
engine command	tidal height
PPU (Portable Pilot Unit) data, pilots' personal device that incorporates GPS, AIS (Automatic Identification System) and heading data. PPU receives vessel dynamic data through a wireless transmitter that is connected to the vessel pilot plug.	visibility
AIS data	mean water level

Table 8. Data provided for remote pilot and the division of data origin between fairway and vessel.

Item		Description
1.	Test ID A	Remote pilotage tests 1.1, 1.2, 1.3, 1.4
2.	Date and time	Dec. 18, 2019 at 09:00-16:15
2.	Brief description	Inbound in Rauma 12 m intelligent fairway
3.	Preconditions for tests 1.1, 1.2, 1.3, 1.4	Sea state: significant wave height 0.5 m Sea current: coming from 310°, speed 0.1 knots Wind: coming from 270°, speed 15 knots Visibility: 10 nm Water level: chart datum Other traffic: none
4.	Piloted vessel	Container ship, displacement 24080 tons, dead weight 15952 tons, draft forward 8.51m, draft aft 9.49m, length 169m, breadth 27.2m.
5.	Configuration of the remote pilot test environment in test 1.1	Communication: VHF Visualization: remotely inclining and rotational camera view from piloted vessel bridge, four camera views from selected fairway positions, Vessel Traffic Service (VTS) display, RADAR image (vessel origin) Vessel conning display consisting of: enhanced GPS position, rate of turn (R.O.T), vessel predictor, speed through water (S.T.W), speed over ground (S.O.G), course over ground (C.O.G), vessel position, propeller pitch, rudder angle, engine command Portable Pilot Unit (PPU) data consisting of: rate of turn (R.O.T), vessel predictor, speed through water (S.T.W), speed over ground (S.O.G), course over ground (C.O.G), enhanced DGPS position, vessel trim, vessel heel, vessel motion aft, vessel motion forward, drift angle, cross track distance, propeller pitch Weather data consisting of: preset simulated conditions (same conditions maintained through all tests)
6.	Configuration of the remote pilot test environment in test 1.2	All above information excluding remotely inclining and rotational camera views from piloted vessel bridge
7.	Configuration of the remote pilot test environment in test 1.3	All above information excluding remotely inclining and rotational camera views from piloted vessel bridge and radar image (vessel origin).
8.	Configuration of the remote pilot test environment in test 1.4	Vessel bridge equipment at full disposal, no access to bathymetric data or VTS display. Pilotage conducted in conventional manner with pilot physically on the bridge of the simulated vessel.
9.	Participants	Remote pilot: certified master unlimited, senior pilot, Finnpilot Pilotage Oy. Experience as a pilot: more than ten years. Piloted vessel captain: certified master unlimited, Finnish, Experience as a navigator: more than ten years. Piloted vessel chief officer: certified master unlimited, Finnish. Experience as a navigator: more than ten years. Simulation arrangements responsible: certified master unlimited, maritime simulation trainer, Winnova maritime training, Finland. Data collection and assessment responsible: paper lead author Janne Lahtinen, master unlimited, doctoral student, Aalto University, Finland.
10.	Test Case (tests 1.1, 1.2, 1.3, 1.4)	Vessel navigating inbound in 12-meter fairway to Port of Rauma turning basin using listed supportive data.
11.	Data collection	Route track, cross track distances, video and voice recording of the piloted bridge, eye tracking data from the remote pilot visual observations.

Table 9. Configuration of remote pilotage tests.

3.3.1 Remote piloting Test 1.

In Test 1, the vessel was remotely piloted using all available aids previously listed. Environmental conditions, participants, and configuration of the test environment are presented in Table 9. Vessel motions were monitored by a PPU (see Table 3). These systems provided information equivalent to GPS. The gyro heading was used to predict the vessel position and orientation ahead of time.

Results of gradual reduction of navigation data offered for remote pilot are described in Tables 10 and 11 as distribution of visual observations in straight and curved fairway parts.

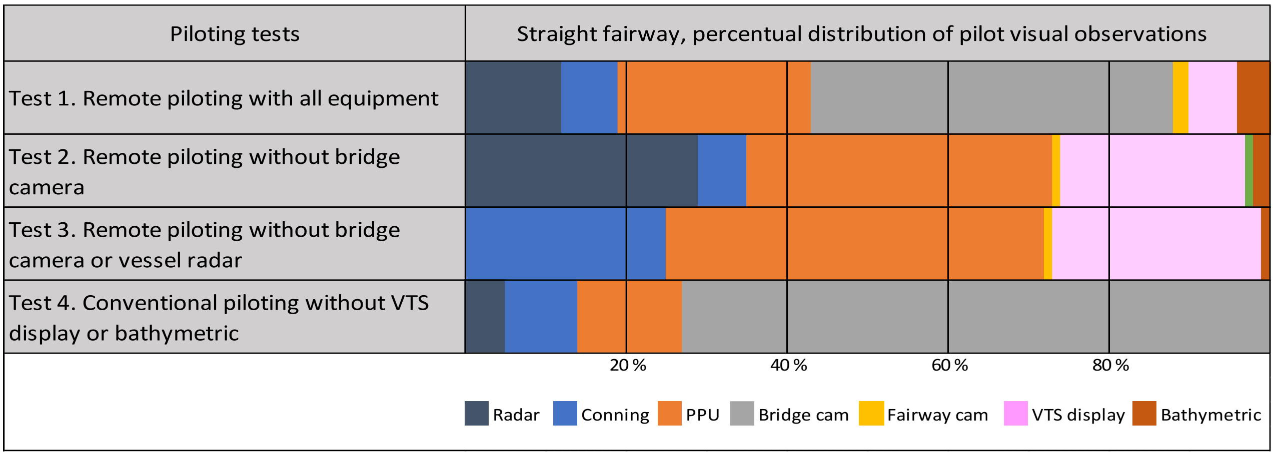

Table 10. Results of simulation tests 1-4 for straight fairway part.

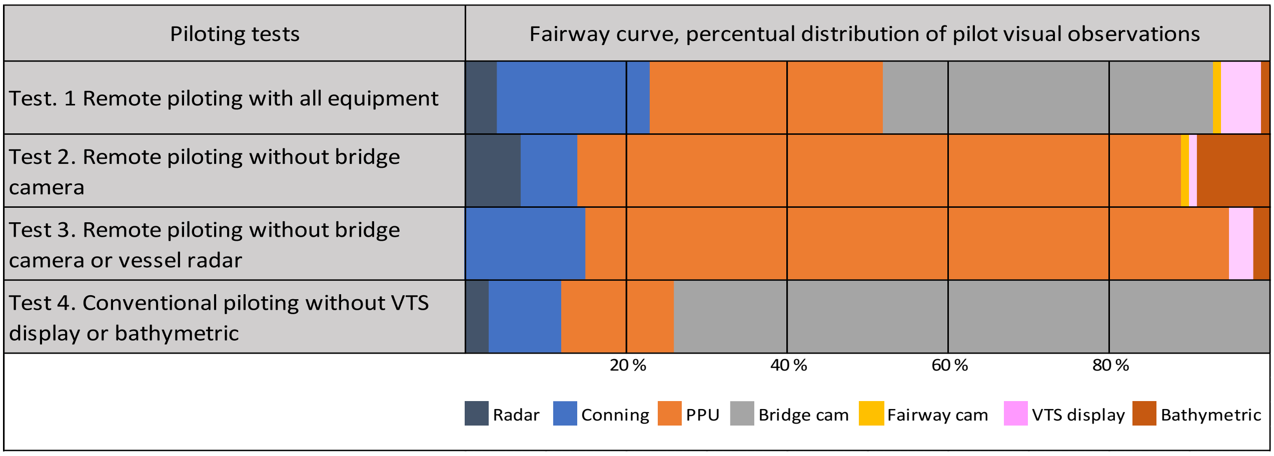

Table 11. Results of simulation tests 1-4 for curved fairway part.

Tables 10, and 11 illustrate the dominant role of the bridge camera during pilotage operations. The time spent not looking at the bridge camera was used to seek confirmation for observations from bridge instrumental aids to navigation. Conversely, the validation of visual perceptions was done via the PPU. In the debriefing after Test 1, the following two key points were sort-listed : (1) the pilot used proportionally less time looking through the windows in the turning section than in the straight part of the fairway; (2) the vessel track illustrated in Figure 5 demonstrates that the vessel drifted to the southern limit of the straight section of the fairway where vessel is to maintain in the center of the fairway between the red and green lines. In figures 5-8 green line indicates southern fairway limit and red line northern fairway limit, respectively.

In the curved section of Figure 5, the vessel was more accurately positioned. The above suggests that visual observation is preferred when available and that instrumental aids to navigation serve mainly to confirm the visual sightings. Considering the results of Test 1 and the reasons behind the KNM Helge Ingstad accident (Lahtinen, 2019), it appears that risk management of visual observations from the bridge is critical, especially in the absence of a bridge camera.

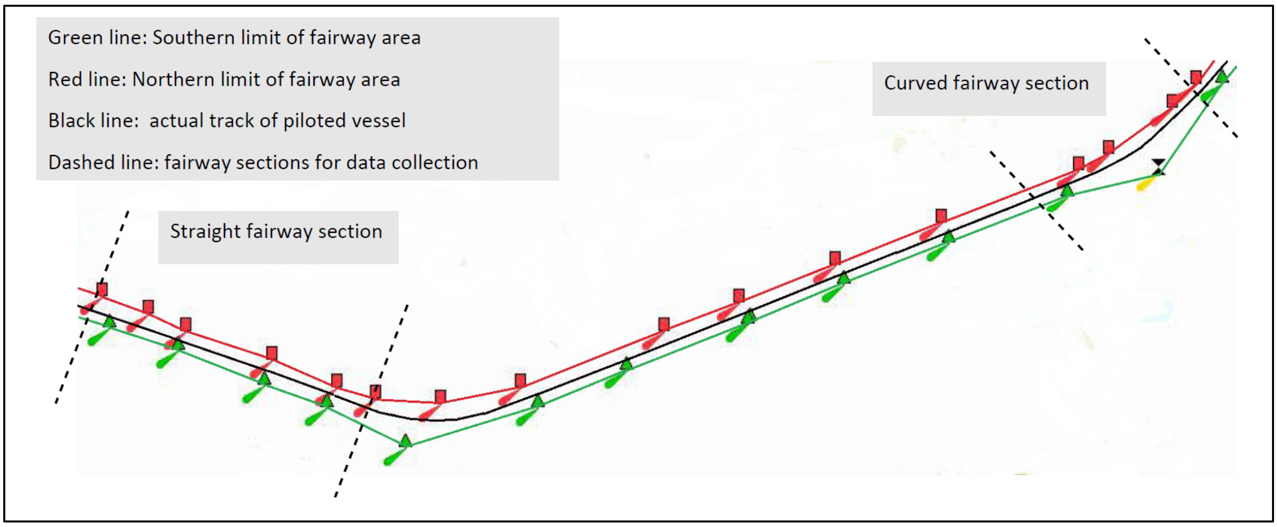

Figure 5. Piloted vessel actual track for Test 1.

3.3.2 Remote piloting Test 2.

In Test 2, the vessel was remotely piloted with all the equipment listed in Table 9, excluding the bridge camera. Environmental conditions, participants, and configuration of the test environment are presented in Table 9. In the straight part of the fairway, the vessel radar image and VTS display were clearly dominant. In the fairway turning section, the PPU dominated operational decision making.

Two key observations emerge from Test 2, as illustrated in Tables 10 and 11. First, the absence of a bridge camera led to excessive use of PPU. Second, during the turning of the vessel, the use of the vessel conning display did not increase. Pilot preference for PPU can partially be explained by his/her familiarity with PPU. The turning of the vessel was conducted almost solely through PPU without seeking confirmation from other devices. In a similar fashion to Test 1, the fairway turning section was again navigated with higher accuracy than the straight section. Taken together, this suggests that familiar to conventional piloting ways of observing surroundings (e.g. eyesight and PPU), are also prioritized in remote piloting.

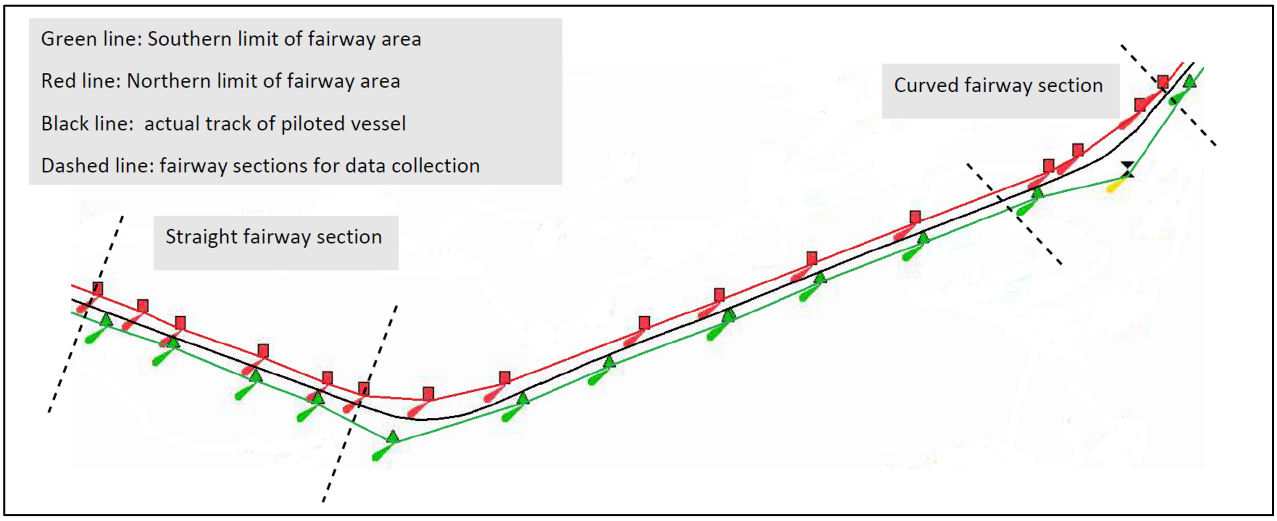

Figure 6. Piloted vessel actual track for Test 2.

3.3.3. Remote piloting Test 3.

To better understand the relevance of replicating the pilot's onboard working environment ashore, a third simulation test was conducted without the navigational radar view from the vessel. In this test, the vessel was remotely piloted with all the equipment listed in Table 9, excluding bridge camera and vessel radar view. Hence, the PPU and conning display were mostly used. Environmental conditions, participants, and configuration of the test environment are presented in Table 9. Two observations emerge from Test 3. First, in both the straight and turning parts of the fairway (see Tables 10, 11) observations between the VTS display and vessel conning display were almost evenly distributed. This suggests that the pilot continuously sought information equivalent to customary aids to navigation (e.g., visual observations and radar). Second, the proportion of PPU observations in the fairway turn was nearly 80%.

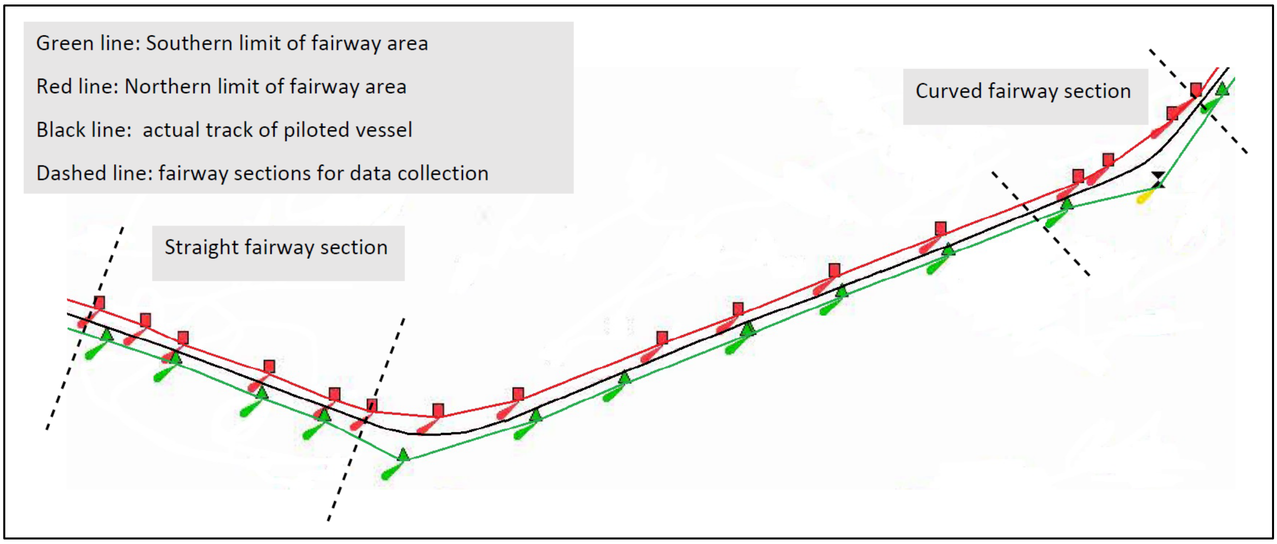

Figure 7. Piloted vessel actual track for Test 3.

During debriefing, the pilot stated that his/her preferred sources of information for remote decision making were, in order of preference: (a) bridge camera view, (b) PPU/vessel radar and (c) conning display. Notably, bathymetric data or the VTS display were reported to be of low importance for normal navigation. The absence of radar or a substitute method for observing vessel surroundings and other traffic would hardly be acceptable for remote piloting. Again, a comparison of Figures 6, 7 and 8 indicates no significant difference in vessel navigational performance in the fairway. In summary, results from the simulation tests suggest that a pilot prefers to rely on information sources he/she is familiar with.

3.3.4 Remote piloting Test 4.

In Test 4, the vessel was conventionally piloted with all bridge equipment and PPU (see Tables 10, 11). The pilot appeared more relaxed, able to easily navigate through the cutting of the corner in way of the turning part of the fairway (see Figure 8). It is noteworthy that in Test 4, the bridge view was not based on a camera view, but on a visual from bridge windows. Moreover, the pilot had no access to a bathymetric display during Test 4.

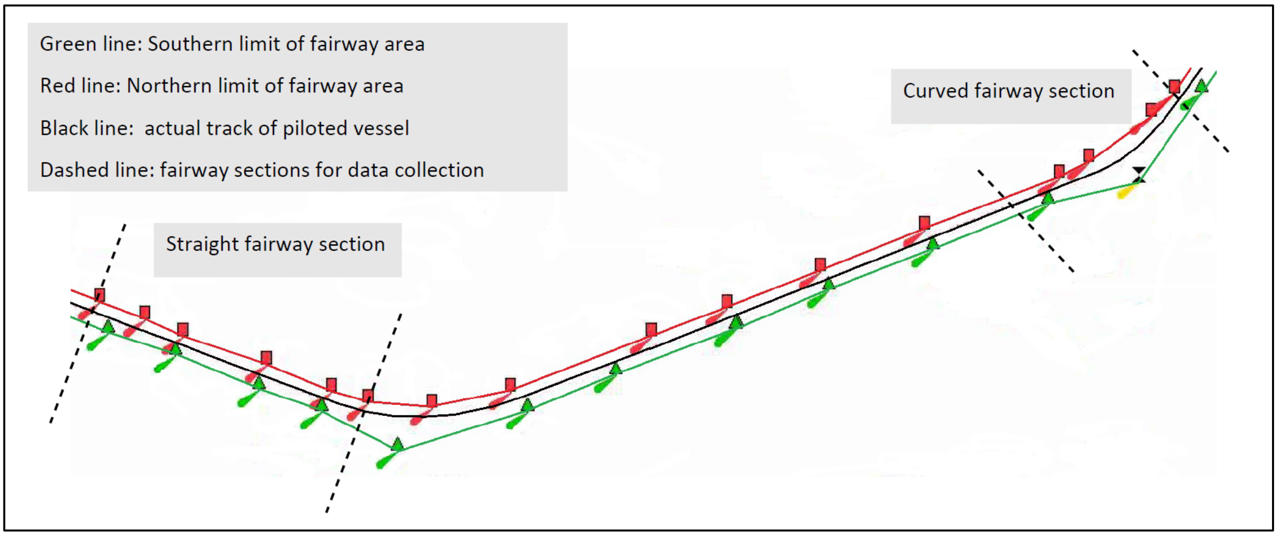

Figure 8. Piloted vessel actual track for Test 4.

3.3.5 Debriefing after simulation tests

The final test session was followed by an immediate debriefing where the captain, the chief officer, and remote pilot shared experiences in an open discussion. The author took notes and for the most part did not participate in the actual exchange of thoughts. The author asked the test crew and pilot to elaborate on the comments provided during the tests and the debriefings after individual simulation tests. A debriefing discussion lasting one hour, and 15 minutes was held in the lobby of the simulation floor. From the perspective of developing a remote piloting operational environment, discussions between test participants raised the following key points:

- The remote pilot reported he could pilot a real vessel in a fairway under given conditions, with a crew having good communication abilities and maneuvering skills.
- The captain and chief officer of piloted vessel stated that the remote pilot made them feel momentarily nervous and distrustful. This was supported by events in a fairway turn during which the remote pilot stayed silent for an extended period prior to turning.
- For those cases that multiple data sources provided the same information, the pilot preferred to rely on a familiar source of information.
- Although visual observations via bridge camera were used when made available, the pilot reported that instrumental information might excel in navigation decision making during piloting. Furthermore, the pilot commented on this being conditional on the availability of a familiar source of information and associated user interface, e.g., PPU.

- A single preferred source of information (e.g. PPU) was highlighted in remote pilot observations. Other sources of information (e.g. conning display) were used to verify the former.

4. Discussion

After the online survey of pilots and interviews of management, it became evident that there are numerous factors that would likely support the development of remote piloting. In light of the survey and interviews, a deeper understanding of how the remote piloting working environment should be configured was pursued. For this purpose, simulation tests with associated debriefings provided multiple operational and organizational focal points. Bruno & Lutzhoft (2009) discussed the necessity to establish pre-conditions for remote pilotage. Along the lines of their work, this study provided further insight to pre-conditions for remote piloting. The online survey, interviews, and simulation tests demonstrated that remote pilotage might be a feasible option, provided that the factors and associated operational thresholds listed below are considered:

- Environmental circumstances are favorable. First, specific fairway features – such as archipelago areas as particularly congested waters – introduce higher demand for positioning accuracy. Second, geographically local phenomena – such as increased solar activity causing disturbances in the GNSS signal – weaken the accuracy of vessel positioning.
- Remote pilot data feed meets the minimum level for robust situation awareness (Figure 3). For example, the piloting of a chemical tanker vessel that poses a high risk for the marine environment is subject to more stringent preconditions than a regular cargo vessel.
- The feeling of trust is maintained between the remote piloting system and the vessel crew. The communication protocol between the piloted vessel and remote pilot considers what information must be exchanged and how information exchange must be timed.
- Crew competency meets demands. The piloted vessel crew must understand the vessel characteristics, can maneuver the vessel safely and crew must be able to adjust the vessel capabilities to the prevailing and forecasted weather. The vessel crew must possess sufficient language skills for efficient communication. The complete operational framework covers all aspects of pilotage. The operational framework must provide decision making support and clear threshold values for different types of vessels.
- Further standardization of actual pilot procedures on the bridge could help predict different party requests thus contributing to safety and the feeling of trust between remote pilot and vessel crew.

4.1 Environmental circumstances and fairway infrastructure

During debriefing after the simulation tests, the pilot reported that favorable environmental conditions are a factor for remote piloting. It is generally known that this is also the case for conventional piloting. However, concerns about environmental factors were not expressed by pilots during the online survey. This suggests that environmental factors are of significance when a decision is made about whether to pilot the vessel or to decline pilotage due to exceeded environmental threshold values. Once a decision is made to commence piloting, environmental factors such as wind become factors for dynamic decision making. Static data associated with the fairway infrastructure may support initial decision making before piloting. Relevant results are demonstrated in simulation tests 1, 2, and 3, which illustrate that limited time was spent observing bathymetry data. In this sense it could be concluded that during tests the pilot appeared not to acknowledge the significance of under keel clearance in the fairway once the decision to commence piloting with the given vessel and her prevailing draft was made.

The role of environmental data varies between the fairway and the port area where the turning of the vessel and mooring maneuvers demand exact information on the weather and limited environmental forces. It is generally known that the availability of weather data in a locality may vary between pilot districts and fairways. In the online survey, available harbor area weather data were limited in comparison to those available for the fairway. This does not necessarily mean that the data were not trustworthy. However, a good and precise understanding of the patterns of harbor area data may contribute positively to the safety of pilotage operations.

4.2 Remote pilot navigation data

Data from simulation test results suggest that navigational decision making may be influenced by the pilot's situational awareness. The results of simulation Test 1 showed that pilots used proportionally less time looking at the bridge camera in the straight fairway section than in the curve. This suggests two things. First, instrumental data is more important than visual perceptions when controlling the vessel rate of turn is significant. Second, replication of navigational bridge audible and visual conditions is not conditional to remote pilot control over the vessel. The results of simulation Test 2 appear to be consistent with those of simulation Test 1, thereby suggesting that in the absence of visual perceptions the use of reliable decision support systems may be important. Moreover, the accuracy of piloting does not seem to increase when the pilot has good visuals from the bridge. Comparison of Figures 4 and 5 indicates no significant variation in vessel tracks between simulation Tests 1 and 2. The debriefing after simulation tests revealed the importance of pilot familiarity with the user interface. This possibly explains the excessive use of PPU. In summary, the study results related to the configuration of the remote piloting user interface suggest that: (1) instrumental monitoring of the turning of the vessel is necessary; (2) familiarity with the navigation data graphical user interface is important; (3) special considerations are essential when visibility is significantly reduced or lost.

4.3 Feeling of trust

Trust was earlier found to relate to communication and sharing of information. Trust, however, is not a reciprocal experience in remote piloting, as is the case in conventional piloting when the captain and pilot simply trust each other. In remote piloting, the captain of the vessel trusts a system, namely remote piloting, not the remote pilot as a person. At the same time, the remote pilot should have a feeling of trust towards the vessel crew. When the pilot is no longer present on the bridge, the crew's sense that the pilot is trustworthy must be facilitated via communication.

Previous studies (Bruno & Lutzhoft, 2009; Hadley, 1999) highlight the importance of trust between the vessel crew and pilot. This is supported by the pilot answers presented in Table 1. The remote pilot must be able to trust the vessel's crew to comply with any pieces of advice given. Simultaneously, the crew trusts the system that the voice represents, not the pilot as a person. Study results provide an association between the requirement for trust and communication. The role of communication in trust emerged in simulation test debriefing, where lack of communication caused the vessel crew to distrust the remote piloting system. Furthermore, the survey and simulation test results indicate the necessity of standardized communication, including the contents and frequency of the messages between the remote pilot and the crew of the piloted vessel.

4.4 Vessel crew competency

This study estimates the ability of the vessel crew based on crew communication skills and competency to maneuver the vessel. Table 2 confirms the important risks associated with a crew's inability to communicate efficiently in English using Standard Marine Communication Phrases (SMCP) and vocabulary. "Crew competence and ability to communicate is the most important factor for successful piloting" (see Tables 4, 5). This statement seems somehow controversial, especially in comparison to the views expressed in Table 4 where only nine pilots appeared to acknowledge the importance of crew training. However, under remote pilotage, bridge management would be largely left to a vessel's crew. Thus, it is thought that a pilot's distrust of vessel crew competence was the main reason behind distrust of remote pilotage operation. "Lowering the necessity to communicate between pilot and crew through advanced technology is key for remote pilotage" (see Tables 4, 5). This statement is supported by the acknowledgment that lack of technological solutions may hinder effective pilotage operations and the demand of pilots to gain remote access to vessel motion data, rudder angle, pitch, speed, and rate of turn. Previous research on remote piloting has largely focused on situation awareness and interaction between pilot and vessel crew (Grech, et al., 2002; Bach, 2009; Betz, 2015; Bruno & Lutzhoft, 2009). This study has revealed the significance of skill level of remotely piloted vessel crew. Without a doubt, modern technology has the potential to enhance the situation awareness of actors, making the pilot less dependent on a vessel crew competency to handle the vessel and their ability to communicate.

4.5 Operational framework

The results of this study reveal potential of operational guidelines as a contributor to operational safety, as found by Betz (2015), Bruno & Lutzhoft (2009), Lappalainen et al. (2012) and van Westrenen (1999). However, findings of this study provide support in the configuration of the operational guidelines of remote pilotage.

The VTS and pilotage management interviews reveal that sound operational guidelines should co-exist with the regulation thresholds set by IMO, IMCO, ISPO, and ICS. It is believed that operational guidelines with a firm grasp of actions taken by a vessel's crew and the remote pilot would inevitably reduce risks and improve piloting performance. This is supported by the online survey answers, which indicated that pilots prefer the use of PPU (see Table 3) and that crews lack the ability to maneuver the vessel in sharp turnings or demanding environmental conditions (see Table 2) without help from the remote pilot. As shown in Table 1, it is necessary to achieve trust between the vessel crew and remote pilot through training. The pilots' skepticism of remote piloting was acknowledged by responses highlighting the distrust of crew readiness and available technology. Possibly, crew readiness could be improved with sound operational guidelines. Taken together, the results of this study suggest, that configuration of remote pilotage operational guidelines should encompass communication protocol, used technology and requirements for the vessel's crew.

4.6 Standardization of remote pilot procedures

Standard remote pilot procedures could be divided into communication and required actions from the vessel crew and the remote pilot. Along the lines of Bruno & Lutzhoft (2009), this study identifies importance of predictability of actions and communication to expect. Timely communication and activities are familiar from aviation and as such could provide a solution to communication challenges in piloting, as found by Bruno & Lutzthoft (2009) and Hadley & Pourjanzani (2009). This study has revealed the connection between operational thresholds and standardized remote pilotage procedures as an important issue for future research.

5. Conclusions

Based on the results presented, it can be said that under controlled conditions remote piloting may be a safe option in the Rauma 12-meter fairway. However, upscaling remote piloting requires understanding of local factors that potentially affect the composition of remote piloting systems, such as fairway features and weather phenomena. Results also indicated that risks related to human behavior and ergonomics are perhaps the most important aspects to be considered when establishing a sound operational framework for remote pilotage operations. The societal importance of implementing remote piloting and utilizing intelligent fairways were included in the Finnish government program in 2019 (Government of Finland, 2019). As such, remote piloting as a commercial service has the near-future potential to serve as a substitute for pilotage exemptions granted to experienced captains. Remote piloting could offer a source of income for piloting companies, forming a commercially attractive solution for all actors. Furthermore, by reducing the need for pilots to commute, remote piloting would optimize the use of expensive expert resources. However, commercial upscaling of the concept to a variety of fairways, environmental conditions, vessel types, and crews requires further research.

During this study, the following limitations were identified : (1) It is important to source suitable remote piloting system modeling and associated risk assessment methods; (2) There is a need to ensure data transfer with minimum latency and effective cybersecurity measures; (3) Critical aids to navigation (e.g., ECDIS, radar, GPS signal, etc.), must be fil-safe, i.e., they should be safeguarded by redundant units; (4) Actions to be taken under extreme operational and environmental conditions (e.g., high sea state, poor visibility, etc.) and in cases of emergency (e.g., loss of power or propulsion) must be determined.

The above calls for established operational thresholds and guidelines for remote piloting, seamlessly connecting the pilot, vessel, VTS operator, and fairway infrastructure under safety management systems. The results from the simulator environment presented in this paper outline how a cost-efficient and diverse platform for the testing of remote piloting could be made useful and usable. As such, it provides a functional foundation for future collaborative research.

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