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Recommendations for the Development of a Legal Framework for Remote Piloting

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ABSTRACT

Technological development allows sea pilots to operate remotely from shore, assisting vessels through areas that are complex to navigate. A Sea pilot (a marine pilot, a harbor pilot, a port pilot, or simply a pilot) is a mariner who advises a master how to safely navigate the vessel and his role is well known in the maritime world. The challenge lies in defining his role when the ship is being monitored via live-streaming cameras. Remote pilotage offers significant cost reduction benefits; however, this mode of pilotage necessitates comprehensive regulations and standardization. It is crucial to delineate the pilot's role, including the commencement and termination of their duties, as well as their legal responsibilities within the regulatory framework. The paper presents tasks for remote pilotage legal regulations, considering that the lack of regulation at the international level could pose significant legal challenges to its implementation.

1 Introduction

The function of the maritime pilot dates back to Ancient Greek and Roman times when captains of incoming ships, to bring their vessels safely into port, employed locally experienced harbour captains, mainly fishermen. With the strengthening of maritime transport, this role became increasingly important. The function of the pilot was very precisely regulated as early as the 19th century.

Thus, the Merchant Shipping Act from 1854 [1], an Act of the Parliament of the United Kingdom, issued on 10 August 1854, together with the Merchant Shipping Repeal Act from 1854 [2], which together repealed several centuries of preceding maritime legislation define: “Pilot” shall mean any person not belonging to a ship who has preliminary; “Qualified Pilot” shall mean any person duly licensed by any pilotage authority to conduct Ships to which it does not belong.

This historically important regulation extensively regulates the acquisition of authorization and payment for pilot services, all in a separate chapter of the Act [1]. Modern regulations have continued the tradition of precise regulation of this important activity.

The International Maritime Pilots' Association (IMPA) describes the marine pilot as a trained expert in ship navigation in specific waters with extensive knowledge of local conditions. Also, IMPA on their web page wrote: “Their role is to guide vessels safely and expeditiously through their area ensuring safety of the environment, people and trade. This is a highly responsible, difficult, demanding, and dangerous job. It is, however, rewarding and highly respected and pilots are considered the elite of the marine professionals [3].”

Certainly, it is necessary to emphasize that the role of the pilot is always only advisory. “The master's position and authority on board of a piloted vessel remain unchanged. The master retains the command over the vessel and has always the power and authority to interfere with the pilot's actions [4]."

Nowadays, when remote-controlled and autonomous ships are becoming a reality, the question arises: is it possible to implement the pilot's service through remote technology, in a way that the pilot performs his advisory role from the shore? This would eliminate the risk associated with physically arriving at the ship and significantly reduce costs since no pilot boat or accompanying crew is required.

The first tests of such models have already been conducted. During 2022, there has been ongoing testing of remote ship piloting systems at Finland's Port of Kokkola. M/S Viikki has been relaying immediate data regarding its navigation and prevailing local maritime conditions back to a remote pilotage hub located in Turku, Finland. Within the framework of the Sea4Value Fairway initiative, led by DIMECC, remote piloting technologies were employed concurrently with traditional pilotage [5].

For instance, while the M/S Viikki is mentioned in the context of remote piloting, it is important to clarify that this vessel is a bulk carrier operated by ESL Shipping, equipped with advanced automation and environmental technologies, and was among the first vessels to participate in remote pilotage tests in Finland. These tests were part of the Sea4Value Fairway project, which focused on exploring smart fairways and the digitalization of pilotage services in the Gulf of Bothnia and aimed to validate remote pilotage under controlled circumstances with real-time data feedback to a remote pilot station in Turku [5].

The Sea4Value Fairway project included multiple pilotage scenarios, both conventional and remote, making it a hybrid testbed for evaluating the operational and legal feasibility of remote pilotage solutions in practice. However, it is true that the project documentation does not always distinguish clearly between these variants of pilotage, nor specify the scope of legal applicability per scenario. To date, only one country has legally enabled remote piloting – Finland, by amending its national Pilotage Act [6]. International regulation does not yet exist – pilotage is governed by hundreds of national regulations from various countries. The absence of international regulation could lead to serious problems with the implementation of this model. Certainly, this possibility requires appropriate technological and legal preparation.

Finland became the first country to legally recognize remote pilotage through the 2019 amendment (Act 51/2019) to its Pilotage Act, which allows licensed pilots to operate from shore under defined technical and operational conditions. While the law enables remote pilotage, it does not explicitly define whether this applies to all three IMO-defined variants of remote/autonomous control or only to conventional vessels operating under remote pilot advisory conditions with crew still on board.

2 Materials and Methods

Given the fragmented regulatory landscape of maritime pilotage, this paper applies a multi-level analytical approach, examining international conventions and IMO resolutions (e.g. SOLAS Chapter V, Resolutions A.159(ES.IV) [8] [9] [10] and A.960(23)) [11] alongside national legislation—particularly Finland's Pilotage Act (940/2003 [6], as amended by Act No. 51/2019) [7] and selected sub-national frameworks such as those of the United States. This comparative overview identifies key regulatory gaps and best practices to support the development of coherent international standards for remote pilotage.

The methodology in this paper combines theoretical analysis and synthesis of legal regulations in piloting, analysis of existing maritime laws, and examples of best practices observed to date. Deductive and inductive methods were used while writing this paper. The deductive method in this paper refers to conclusions from general to individual, i.e., it explains facts and different acts in maritime law, to predict future events in the field of remote piloting, to improve existing facts, and propose amendments to the law.

The inductive method has helped authors to conclude from general facts based on special or individual instances. For example, piloting is an extremely challenging and dangerous job, and it may be that the time has come to employ technological advancements to implement remote piloting more broadly soon. This could help avoid the loss of pilots who must transfer from a pilot-boat to a large ship under difficult conditions.

Also, an empirical study was carried out to explore several possible problems that can be encountered while getting on board the ship, concerning the bad weather conditions or the size of the ship and reasoning for several possible ways to mitigate issues of remote pilotage. What further facilitates such issues can be found in the following conventions, resolutions, rules and the situations occurring with pilotage, and which are mentioned in this paper.

3 Role of Maritime Pilot

Far back in 1968, the IMO recognized the importance of hiring qualified pilots in port approaches and other areas where specialized local knowledge is needed and then adopted Assembly Resolution A.159 (ES.IV) Recommendation on Piloting [8].

Special attention to this matter has been dedicated and contained in Chapter V of the SOLAS Convention [9], which discusses the safety services to be provided by contracting governments and sets out provisions of an operational nature that generally apply to all ships on all voyages, no matter the size but are also the subject of IMO resolutions relating to the embarkation and disembarkation of pilots in large ships (A.426 (XI)); and also, in pilot transfer arrangements (A.667 (16)). Furthermore, the IMO has adopted the Recommendation on Pilot Transfer Arrangements (Resolution A.1045 (27)) [10] and approved the Pilot Boarding Request (MSC.1 / Circ.1428) [12] with required boarding arrangements for pilots.

Certainly, IMO Resolutions have supported the role and use of pilots in specific maritime areas where in-depth knowledge and familiarity with the region are essential, and where docking without a pilot familiar with the area is challenging.

In order to be able to analyze the issue of remote pilotage first we need to explain the role and powers of the pilot in classical pilotage, where the pilot boards the vessel.

Pilotage may be mandatory and optional. Luttenberger writes about this: during the pilotage, the pilot is obliged to guide the ship and give expert advice to the master of the pilot ship regarding the ship's guidance, mooring, and anchoring, and to warn about the navigation conditions and regulations applicable to the area where the ship is piloted but also to inform the Harbor Master's Office via radio about the commenced and completed pilotage. If pilotage is optional, after exchanging the necessary information, the master will enable the performance of the pilotage activity and constantly monitor its work during the pilotage. In the case of compulsory pilotage, the master commander allows the pilot to perform pilot activities, but it is permissible for the master of a liner, who is well acquainted with the port in question, to continue to personally guide the ship through the compulsory pilotage area [13].

As Luttenberger explains, the advisory nature of the pilot's role stems from the need to maintain the master's ultimate authority on board the vessel, even in cases of mandatory pilotage [13]. For example, Croatian legislation, in its new Ordinance on Maritime Pilotage 2025. specifies in Article 22: "During pilotage, the pilot shall not leave the bridge of the piloted vessel before the vessel has completed its manoeuvring or navigation through the area of compulsory coastal or port pilotage, regardless of whether the master of the piloted vessel accepts the pilot's advice concerning the navigation or manoeuvring of the vessel." [14]

As Bruno and Lützhöft point out, the concept of remote pilotage still lacks a single, clear definition, despite various attempts by professional associations to describe it precisely [15]. For instance, Koester et al. define remote pilotage as "an act of pilotage, carried out by a licensed pilot, from a position that is not on board of the ship that is subject to the pilotage" [16].

At present, this service is implemented in parallel with traditional pilotage and is not intended—according to current regulatory frameworks—as a full replacement for conventional pilotage. Nevertheless, as this paper argues, remote pilotage has the potential to gradually replace conventional pilotage in specific contexts, subject to the development of adequate legal and technical standards, as it can reduce operational risks and costs associated with boarding and disembarking pilots at sea.

Interestingly, in cases of mandatory pilotage, the pilot is required to remain on the bridge and continue performing pilotage even if the master does not follow the pilot's advice. This reflects the essential safety function of pilotage within the broader framework of maritime navigation.

There is also the possibility of exemption from the obligation to use the services of a pilot, in most Member States of the European Union, legislation provides the possibility of some form of exemption from pilotage, either through exemptions in the regulations for compulsory pilotage or by issuing Pilotage Exemption Certificates (PEC) [17]. However, Member States are reluctant to allow these exceptions, despite the Commission pointing to protectionist measures as early as 2009 [18], and then commissioned and published a document in 2013, analyzing the possibility of Pilotage Exemption Certificate [19]. The Pilotage Exemption Certificate (PEC) is a certificate that provides for suitably qualified crew (usually the shipmaster) to navigate their vessel instead of being compelled to use a maritime pilot when navigating in compulsory pilotage areas.

According to 2013 document Support study for an impact assessment on: "the establishment of a European framework for granting PECs" (Page 18) [19], in some countries, regions, or ports it is not possible, or it is extremely difficult for a shipmaster to apply for and obtain a PEC – thus it can happen that a shipmaster with sufficient qualification and experience must unnecessarily be advised by a pilot.

Member States are reluctant to provide exemptions from the pilotage obligation, to allow their pilots higher earnings. The above-mentioned Commission Communication 2009 states: "Pilotage services can be a serious problem. Vessels on SSS run calls regularly at the same ports, and their masters are familiar with the physical features. Nonetheless, in many cases pilot assistance is compulsory. While some countries do offer a Pilotage Exemption Certificate (PEC), there are often national requirements that make a PEC difficult to obtain [18]." When we think about the function and role of pilots, we must be aware that behind safety sometimes lie specific financial, lobbying, and political interests.

In addition to being extremely responsible, the job of a marine pilot requires enormous knowledge and experience, and it also requires appropriate physical fitness which can be and in some cases is very dangerous.

IMPA states how most often the pilot boards an inbound vessel from a pilot launch, by climbing a ladder rigged over the side of the vessel. Sometimes it is necessary to board the use of helicopter transfer. Both methods can be very hazardous [3]. Pilots are still being faced with deficiencies in boarding and landing vessels, even with these days standards which include IMO Pilot transfer arrangements [20]. That document states that ship designers are encouraged to consider all aspects of pilot transfer arrangements at an early stage in design.

Although there are elaborate protocols for boarding and landing pilots (the ship is placed in the lee, and the officer on guard is obliged to check that the pilot ladder is properly installed) [12], the possibility of injury, especially in severe seas, always exists. Maritime Mutual Risk Bulletin Notice: "The boarding and disembarkation of a ship's pilot, often in challenging weather conditions, is a unique and hazardous exercise. The incidence of injury and fatalities during ship to pilot boat transfers is substantial [21]."

As an example of the dangers that maritime pilots face, International Maritime Pilots' Association (IMPA) 2020 Pilot Ladder Safety campaign results are presented. The IMPA conducted a safety campaign in 2020 that focused on checking whether pilot ladders used for embarking and disembarking pilots on ships adhered to international safety standards. Of the 6,394 ships inspected, 12% of ships did not meet standards. The highest rate of ships not meeting the necessary safety requirements (58.06%) was recorded in the Middle East. In contrast, South America had the lowest rate of ships failing to meet the standards, with only 6.77% [22].

Also, the pilot boat must be ready, and able to reach the ship that needs a pilot under all conditions. This makes the operation expensive, because on the high seas, the pilot boat must be reasonably large and with a larger number of crew members. Working in multiple shifts requires not only more pilots but also the entire crew. Therefore, arriving at the meeting point (pilot station), and maneuvering also takes time, which makes the pilot's service even more expensive.

4 Technological foundations and legal frameworks

The International Maritime Organization (IMO) defines four degrees of autonomy in maritime transport:

- Level 1: At this level, ships have automated processes and decision support systems. Seafarers are present on board to operate and control the ship`s functions, although some processes may be automated and temporarily unattended.
- Level 2: This grade includes remote-controlled ships with seafarers on board. The ship is controlled from a remote location, but there are seafarers on board who can take control if necessary.
- Level 3: Ships of this grade are remote-controlled without any seafarers available onboard to take over control if necessary. The ship is controlled and operated from a remote location.
- Level 4: Fully autonomous ships operate independently, as their operating system can make decisions and determine actions without human intervention [23].

The above classification shows that in the first two degrees there are seafarers on the ship, while in classes 3 and 4 there are no seafarers, and the automation is completely without seafarers.

Each degree of autonomy is associated with different scenarios as shown Figure 1, including the presence of a pilot on board, the remote pilotage function, the assumption of the pilotage function by the ship operator and fully automated functions by artificial intelligence (AI). The diagram outlines the legal framework and regulatory requirements needed for each scenario and describes the division of responsibilities and the conditions that operators must fulfil to take over the role of pilot. It also addresses critical issues of responsibility, particularly concerning AI decisions and errors.

For Degree One, the regulations still in place for commercial vessel pilotage and they are primarily governed by international conventions like the International Convention for the Safety of Life at Sea (SOLAS) and are then implemented through national laws. According to normal commercial vessels pilotage can be done in two ways: with presence of pilot on board or in some situation's pilotage can be done remotely via remote locations. In the case of remote pilotage, regulations define when it starts and ends and who is responsible for unwanted situations in a case they occurred.

Degree Two combines elements of Degree One with scenarios where the ship operator assumes pilotage duties remotely. For this scenario, regulatory provisions are still lacking. Degree two has some questions which need to be answered: When pilotage begins and the pilot's responsibilities to the captain of the ship in a case there is not pilot stations? Who is responsible: pilot or operator in a case they are both operating vessels remotely? If operator is taking role as a pilot (PECs) what kind of knowledge he needs to have?

Degree three defines that remote operator will be master of the vessel but it a context of pilotage, it remains unclear whether the remote pilot assumes control of the vessel or provides navigational advice to remote operator. If the remote operators should be eligible for Pilotage Exemption Certificates it means that existing PEC framework should be adapted.

Degree four looks at accountability for AI-driven decisions and errors, including the impact on insurance. Autonomous vessels ought to be exempt from compulsory pilotage, in a case of vessel being driven by AI, without crew and with decisions made by AI systems it is assumed that pilotage will be implemented in system.

This structured approach helps to understand the challenges and the need to adapt the legal framework to the increasing autonomy in the maritime sector.

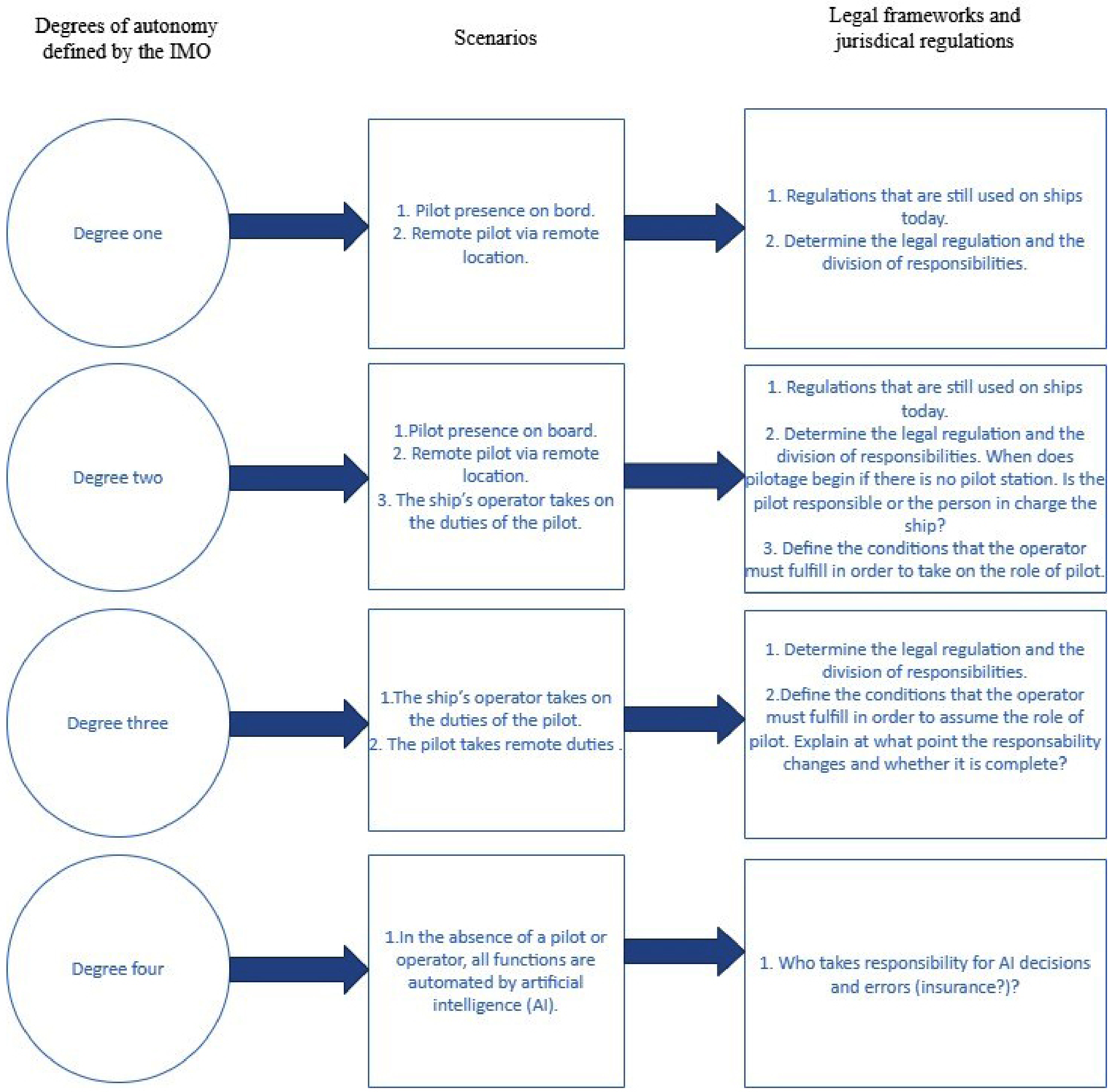

Figure 1 Degrees of autonomy vessels (IMO) and possible scenarios.

The first two degrees are an intermediate stage of autonomy, which is defined as follows: "The ship is controlled and operated from shore or another ship, but a person trained for navigational watch and manoeuvring of the ship will be on board on standby ready to receive control and assume the navigational watch [24]." This significantly facilitates legal regulation, as there is no need for the ship to switch to autonomous navigation in the event of loss of remote control. Then the navigation is taken over by the master and the crew on board. Responsibility at this level lies with the ship's captain as it was already mentioned

In Level 1 presented in Figure 2, the existing legal regulations are adopted, as the crew and captain are on board. Level 2 introduces the possibility of remote pilotage, raising questions about who bears responsibility: the remote operator, the remote pilot, or both. It also requires consideration of the specific technical systems and training standards needed, as well as the scope of legal liability associated with remote pilotage.

In the area of maritime pilotage, the transition to autonomy levels three and four represents a profound departure from traditional practices, with significant implications for navigation and ship management (Figure 3).

Level 3, for which there are two possible scenarios, namely that the operator becomes the pilot or that the pilot takes over the maneuvering of the ship from the operator. Since in this case the pilot is not physically on board the ship, it must first be determined when the pilot's role begins and who is responsible in the event of an undesirable situation (incident, accident). It is also necessary to define the conditions that the operator must meet when taking on the role of pilot (a certain number of entries into the port, knowledge of the area, passing a test, etc.). In the case of a successful entry, the

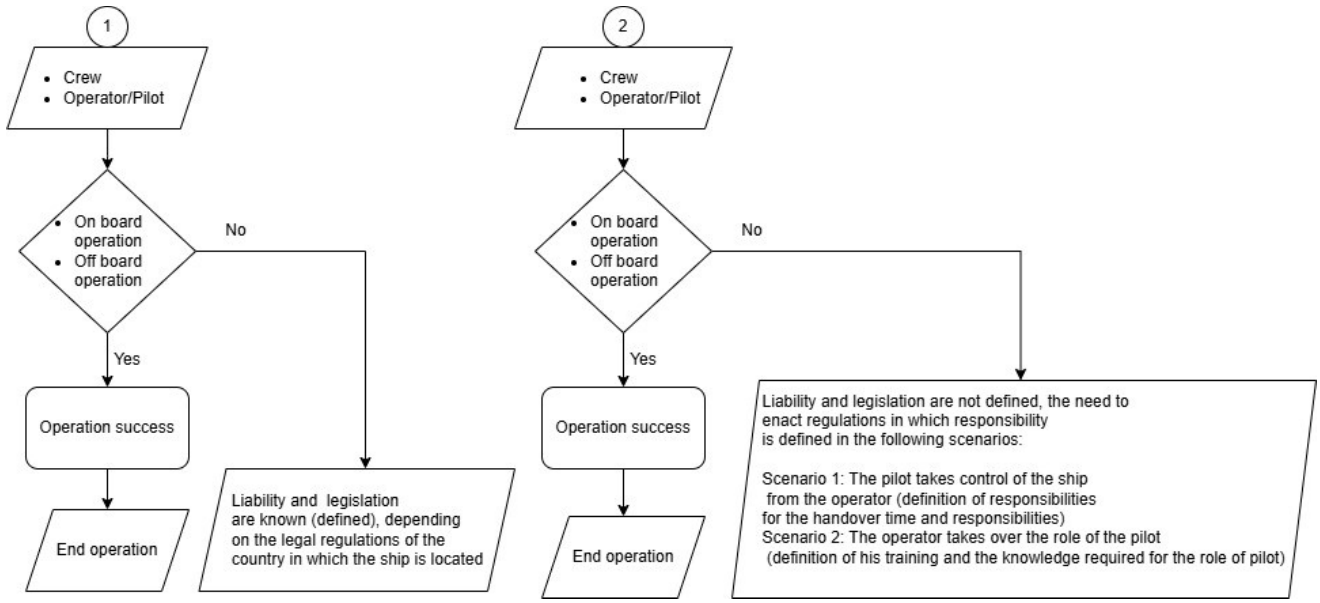

Figure 2 Scenario flowchart in levels one and two

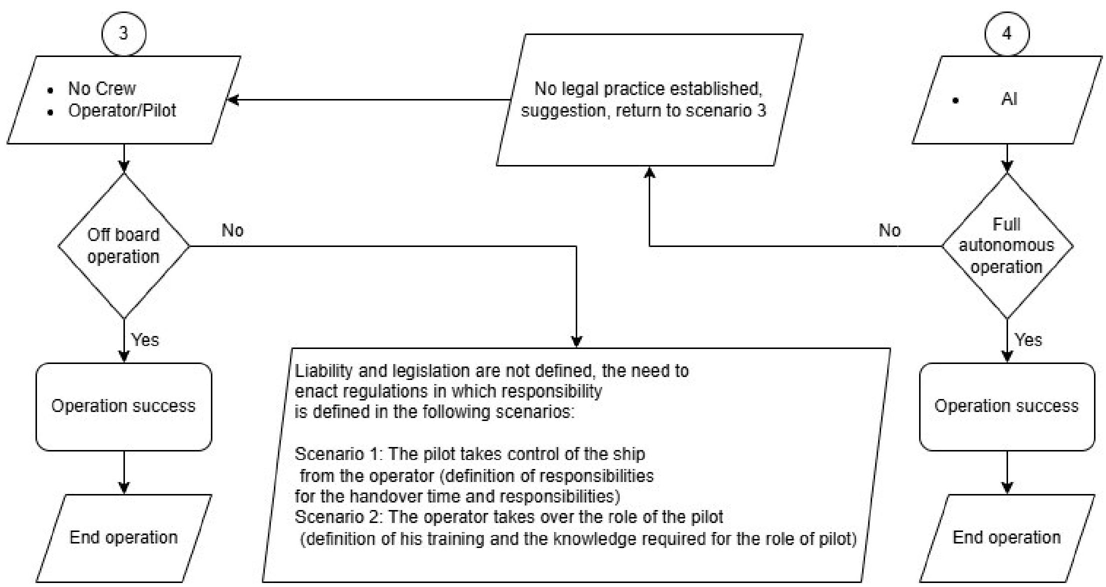

Figure 3 Scenario flowchart in levels three and four

determination of responsibility for an undesirable event is not so important, but the problem arises in the case of an undesirable event due to the lack of a captain in the legal sense of the word (a person who takes responsibility for undesirable consequences).

Level 4 represents an operational scenario using artificial intelligence, where the ship is fully autonomous, and as a measure in the event of an unsuccessful operation, it is suggested to return to level 3, i.e., to download possible scenarios and legislation from level 3. Certainly, level 4 is necessary to define who takes responsibility for the failure of artificial intelligence in the event of a maritime accident, marine pollution and damage to the ship, ships or third parties.

The role of the pilots changes fundamentally on the third and fourth levels, where the ships are remote-controlled without seafarers on board. Traditionally, pilots have played a crucial role in guiding ships safely through complex waterways and harbors, using their local knowledge and experience to navigate in difficult conditions. However, in a scenario where vessels are remotely controlled, the need for pilots on board decreases significantly. Instead, shore-based operators equipped with advanced navigation instruments and real-time data can take over the tasks traditionally performed by pilots. This shift has the potential to streamline pilotage services, minimize costs and improve efficiency, but also raises questions about the future role and employment prospects of pilots at sea. While the abolition of pilotage may bring benefits in terms of operational efficiency and safety, it also presents challenges in terms of regulatory compliance, risk management and stakeholder acceptance. The absence of human oversight brings new complexities in terms of liability, emergency response, and decision-making in unforeseen situations, requiring robust frameworks and industry-wide collaboration.

Also, Geoff Topp in The Pilot magazine mentions that the pilot's role in conducting the navigation is still relevant that he is the guardian of port infrastructure and the local environment, and that his role is sometimes wrongly reduced to focusing only on the ship on which he is on board. This ignores the need to adjust the passage dynamically to the work of all other movements in the port with the continuous presence of the safe passage of the ship on which he is located [25].

It is necessary to enable a fast data connection between the ship and the shore, specifically, the facility from which the pilot manages, i.e., advises the master. This is technically possible in several ways today. Satellite operators such as IRIDIUM have upgraded their network to enable fast data communication, suitable for autonomous vessels [26].

'The responsibility of the pilot should be limited by law if any technical or communication problems occur, or the operational procedures are not executable' mentioned Sanna Sonninen from Finnpilot [27]. Commercial widely available GSM communications are getting faster, especially with the introduction of the 5G protocol. Certainly, when choosing technology, it should be considered that commercial GSM network operators have a relatively long recovery time in case of failure, under their general terms of service that do not have to be suitable for such systems where a high level of service quality is expected. The pilot needs to be provided with a fast data connection so he can have live camera footage from the ship, the data necessary to control the ship (data on navigation and electronic devices on the bridge, external factors, etc.) and two-way voice and possibly video communication.

Additionally, IMPA Guidelines state that PPU (Portable Pilot Unit) is brought aboard the ship by the pilot, and it is used in conjunction with other mandatory marine radiocommunication and navigation equipment on the bridge, as a tool to assist the local pilot in the safe navigation of the vessel. This is achieved by installing a series of navigation sensors with an electronic map and display. The sensors are usually GNSS (with or without magnification), AIS interfaces, and speed generators. PPU can be quickly set up on a bridge by simply setting up navigation antennas and interfaces. Other information usually includes data on tide and depth and is specific to a particular port [28].

Today, there are no technological barriers to meeting these technical requirements. Remote-controlled ships have been tested for years. For example, tug Svitzer Hermod which in February 2017 carried out the first fully remote navigation in the port of Copenhagen. The ship was equipped with remote commands and cameras, and there was a commanding station on the mainland surrounded by monitors and other navigational equipment. Sailing through the harbor proceeded without any problems [29]. In 2020 Samsung Heavy Industries managed the tug that was located 150 kilometers from the coast [30]. News of similar experiments has become frequent in recent years, and the results successful. Therefore, we believe that the issue of remote pilots is primarily a matter of standardization of technology and legal regulation and that it is possible to achieve with today's technology.

Remote pilot control can have another advantage. Pilots must meet high health standards. According to IMO's "Recommendations of training and certification and on operational procedures for maritime pilots other than deep-sea pilots" [11] each pilot should satisfy the competent pilotage authority that his or her medical fitness, meets the standards required for certification of masters and officers in charge of a navigational watch. This can mean the early retirement of an experienced pilot and the associated costs (pension insurance). With remote piloting, a pilot can be active up to the legal retirement age.

5 Proposal for future legal regulations

5.1 Basic legal framework

The role of the pilot is extremely important because the pilot significantly increases the safety of navigation in front of ports or places where navigation can be dangerous, but his role is essentially advisory, even when directly operating the ship. Even when the pilot effectively controls the vessel during pilotage, this does not alter the basic rule, the pilot is only the advisor [31].

Therefore, in both mandatory and optional piloting, the master is left with all the classic duties and responsibilities – the master (by long-established maritime tradition commonly called the captain) is responsible for the safety of the ship i.e., maintaining the seaworthiness of the ship. The master has certain public authorities; he oversees all personnel, in charge of issuing commands, but also in charge of the entire vessel, the crew, other person on ship and cargo [32].

The fact that the role of the pilot is primarily advisory and that the entire crew with the master is on board during the pilotage which significantly facilitates the legal regulation of the remote pilot service, with the need to regulate autonomous navigation. While with autonomous navigation and even remote navigation, numerous legal issues arise that have already been described in the literature [33], the introduction of a remote pilot requires significantly less regulation, the entire crew is still on board, together with the master who still operates the ship and has the right to make the final decision.

All the above does not mean that remote pilotage can be introduced without proper regulatory adjustments. This is not a substantial change like the one when they built an unmanned ship where decisions are made by a computer rather than a master. Remote pilot means operating a ship from a remote location, which the master can take over at every moment.

Remote pilots, similarly to traditional maritime pilots, perform an advisory role and do not assume command over the vessel. This principle aligns with long-standing maritime legal tradition and is confirmed in national regulations such as the Croatian Ordinance on Maritime Pilotage [14], which states that the pilot advises the master, who retains full command and responsibility during pilotage. The same logic applies to remote pilotage: the remote pilot does not take operational control, but provides navigational advice based on real-time data transmitted from the vessel.

The legal liability of remote pilots should therefore be considered analogous to that of traditional pilots. In most jurisdictions, pilots can be held liable for gross negligence or willful misconduct, but not for ordinary navigational errors, given their advisory capacity [4], [13]. However, questions of liability may become more complex if technical or communication failures occur during remote pilotage. In such cases, liability may be shared or mitigated based on the responsibilities of other stakeholders, such as the shipowner, the port authority, or the technology provider. Future regulation should clearly delineate liability boundaries, possibly following the model of the aviation industry where similar remote advisory services exist [34].

Regarding the technical prerequisites, remote pilotage does require ships to be equipped with certain systems to enable safe and effective communication. Although basic navigation systems (AIS, ECDIS, radar) are already in place on most vessels, remote pilotage also depends on:

- high-resolution, real-time video feeds from multiple shipboard cameras,
- secure and reliable voice/data communication links (preferably with redundancy),
- continuous transmission of navigational and environmental data (e.g., wind, current, speed).

While the pilotage center may be well-equipped, the vessel itself must meet minimum technical standards to allow for safe remote operations. These requirements must be standardized and codified at the international level, ideally through IMO guidelines or conventions [35], [38].

Finally, the ship's master retains the right to request a conventional pilot instead of a remote one, particularly if the technical or operational conditions onboard are not met, or if the master considers it necessary for navigational safety. Remote pilotage must not restrict or override the master's discretion and command authority [14], [13] [32].

5.2 Future regulation

Generally speaking, two aspects will be especially important in the future: (1) the communication between the pilot (whether on the ship or onshore) and the ship along with its shore-based operator; and (2) the scalability of the ship's navigational systems to enable intervention by various shore-based systems at ports and straits, allowing pilots to operate the ship remotely if needed [35].

The greatest obstacle, potentially exceeding the technological challenges of implementing remote piloting, is the lack of international regulation for pilotage. The IMO has published certain technological recommendations, as mentioned in the text, but pilotage is not regulated by IMO regulations or other international conventions – rather, it is governed by hundreds of national regulations. Furthermore, many countries regulate this activity at a lower level. For instance, in the United States, a total of 36 out of 50 states regulate this activity, with some states having multiple regulations. For example, Texas regulates piloting at the level of regional pilotage authorities, of which there are six [35]. The challenges of regulating this activity at an international level will be immense, and without international regulation (an international convention), the strengthening of remote piloting cannot be expected. It requires specific procedures and technological standards that must be uniform to ensure the safety of the process and the security of communications.

Given that Finland remains the only country to have explicitly regulated remote pilotage through its national legislation—specifically by amending the Pilotage Act in 2019 (Act 51/2019) [7] it would be valuable to examine this legal framework in more detail. The Finnish model provides practical insight into how remote pilotage can be integrated into existing legal systems while maintaining safety and professional standards. As such, it may serve as a foundation or model law for other maritime nations considering similar legislative reforms. Comparative analysis of the Finnish legal provisions could help identify transferable principles and necessary adaptations to different regulatory contexts, especially within the EU or IMO member states.

5.3 Stages of regulation

5.3.1 Timeline

What kind of changes are necessary to introduce a remote pilot? We will divide them into several stages.

1. Harmonization of the legal framework at the international level,
2. Standardization of communication protocols and equipment,
3. Introduction of equipment licensing after standardization,
4. Verification of communications in the field of piloting,
5. Development and implementation of new, precise procedures,
6. Additional training for pilots to be ready to perform coastal piloting services.

5.3.2 Legal framework at the international level

Today, there are thousands of legal frameworks worldwide that regulate piloting. Some countries fully regulate the piloting system, some regulate the licensing and designate areas of mandatory piloting, leaving many aspects to entrepreneurs, and in some places, regulation is given to federal states, provinces, or even lower levels of government. In such a system, it is not possible to expect the systematic implementation of any model of remote piloting. Therefore, the first step is to regulate this activity at the IMO level creating an appropriate working group to propose a legal framework at the international level; either within one of the existing conventions or by adopting a new international convention.

5.3.3 Standardized communication protocols

It must be ensured that the ship can establish a connection to the pilot and that other necessary data is properly transmitted in both directions. Ensuring a reliable connection between ships and remote pilots is crucial for the safe and efficient conduct of maritime operations. This requires not only standardized communication protocols, but also robust mechanisms that ensure seamless transmission of critical data, including real-time imagery, telemetry and other relevant information. Such standards should be regulated globally and independently of manufacturers, for example along the lines of ISO (International Organization for Standardization) standards. The development of multiple independent proprietary solutions should be avoided.

5.3.4 Equipment licensing

Approval and inspection procedures for equipment must be prescribed. Cameras, sensors, and other equipment must comply with the relevant technical standards and be tested. For example, whether cameras of the required quality are installed. Inspection of equipment is particularly important if the vessel has a remote control. Regular inspections, checklists, and inspection certificates must be developed. Given the importance of such communication in remote piloting, the experience of the aviation industry can be drawn upon.

Conducting regular audits and quality control measures will help maintain the integrity and reliability of the equipment over time. In addition, promoting transparency and accountability in the inspection process can increase stakeholder confidence and improve overall safety standards in the industry. Collaboration with technology manufacturers and research institutions can also facilitate the development of innovative solutions to new equipment inspection and compliance challenges.

5.3.5 Check communications in the field of piloting

It is necessary to introduce a check of communications in the field of piloting. Ports and other areas where pilot service is required must have secure communication in practice. It must not happen that due to the characteristics of micro-location (e.g., tall buildings, islands, fjords) part of the area is left without a signal. Such areas should be marked as suitable for remote piloting.

Such sensitive communication cannot rely on a standard GSM network. Commercial GSM networks do not fully cover sea areas and have the right to temporarily suspend the provision of services in accordance with their general conditions (bad weather, power outage and similar).

5.3.6 New procedures

It is necessary to prescribe that the piloting service can be performed remotely, but a certain number of hours of trial remote piloting should be prescribed in order to gain appropriate experience and training, and only then allow remote piloting in practical situations with the help of analyzing tools and different continuous measures to increase data exchange and utilization; (such as monitoring weather conditions, deviation reports, ice information, coastal radar data, ship's route plan, etc.) [27], to enhance pilotage.

Remote mode also requires reengineering of the harbor pilot's business process. For example, the formal start of pilot work in practice is very simple: shaking hands with the master [31]Some self-explanatory procedures while the pilot is physically on the bridge, in remote operation must be precisely defined. Pilotage is a process (interesting, in literature pilotage is usually not described as a process) [30]. To provide processes of good quality, remote piloting in our case, we need to understand processes well enough to be able to apply and eventually improve them. Process analysis and then modelling are an important instrument for facilitating every complex process [36].

5.3.7 Training

It is necessary to develop training procedures for pilots and bridge crews at sea. Remote work has its own specificities, and all parties involved need to be trained and educated. The future development of autonomous systems in the maritime industry requires a flexible and proactive approach to education and training [37].

It is important to develop a curriculum that includes the specific skills required to work with autonomous systems, such as technology understanding, risk management, and emergency procedures. The creation of simulations and virtual environments for future pilots is also necessary to gain practical experience under controlled conditions. Continuous training and knowledge updating are critical to keep pace with rapid technological advances and regulatory changes. Regular training and exercises that focus on collaboration between pilots and bridge crews will improve pilots' ability to adapt to the unique challenges of remote operations. Integrating real-time feedback mechanisms into training programs can provide valuable insights into performance and areas for improvement. This approach will ensure that all stakeholders are prepared for safe and efficient operations in the future of autonomous navigation.

5.4 Regulation stakeholders

Certainly, an important role is played by the International Maritime Organization, starting with the establishment of remote pilotage standards. Mandatory pilot boarding arrangements are described in SOLAS Chap V Reg 23 which need to be upgraded [38].

The main issue is the establishment of standardized procedures for how remote pilotage should work. Remote pilotage could cut down expenses by 50% while saving on pilot boat maintenance and fuel [15]. As Ujkani et al. noted, one of the benefits of the introduction of remote pilotage is the reduction in the risk of accidents and injuries during pilot transfers, as the physical presence of a pilot on board a ship is no longer required [39]. Also, as per Finnish study additional benefits include greater scheduling flexibility and time savings [40].

After that, it is necessary to adjust the national regulations.

Self-regulation should not be forgotten. There is ISPO (International Standard for Maritime Pilot Organizations), which is a standard of "best practice for pilots and pilot organizations, improving safety and quality", the last revision was in 2015 [41].

Also, a set of communication data needs to be standardized. In today's practice, there are no formal starting ceremonies where pilots start doing pilotage. When the pilot arrived on the bridge, the ship's master greeted the pilot and sometimes they discussed route operations. On the cruise, ship master gave to pilot more data about the ship and course [31]. If necessary (for example bad weather) the pilot will probably ask for more data. Pilot communicates personally with the master. In remote piloting, the pilot would need to receive a standard set of data before performing his duty. That set of data needs to be standardized.

The introduction of remote pilotage raises an important question regarding the applicability and potential adaptation of the Pilotage Exemption Certificate (PEC) framework to remote operations. In remote pilotage scenarios, especially where shore-based operators or systems are engaged to guide vessels, there may be opportunities to extend or adapt the PEC concept. For example, experienced remote operators who meet equivalent knowledge and competency criteria, such as familiarity with the pilotage area, successful completion of standardized training, and a proven safety record, could be granted a form of Remote Pilotage Exemption Certificate (R-PEC). This would effectively authorize them to perform pilotage tasks remotely under a formalized, transparent regime.

However, such adaptation must be approached carefully. Unlike traditional PECs, remote pilotage involves intermediate decision-making and reliance on technology, which introduces new risks and accountability challenges. Therefore, any extension of PEC-like schemes to remote operators would need to include:

- robust technical standards for remote pilotage systems,
- mandatory training and certification for operators,
- clear delineation of legal liability and responsibility,
- and harmonization at the international level, preferably through IMO instruments.

While there is currently no international framework for remote PECs, this topic warrants further regulatory development, particularly in jurisdictions actively implementing or testing remote pilotage models, such as Finland.

6 Conclusion

We are in a period of significant changes in maritime affairs. Following onboard automation, which has allowed for the reduction of crew members, the introduction of remotely controlled ships and subsequently autonomous ships represents the greatest change in maritime transport since the introduction of the steam engine in the 19th century [42].

Despite all the technological advancements brought by modern development, the job of a maritime pilot remains dangerous. The pilot must board ships on the open sea, sometimes in very challenging conditions, to navigate them through dangerous straits or into ports. Despite all measures, accidents still occur, and data show that prescribed safety measures and standards are sometimes not applied. The ability for a maritime pilot to perform their job remotely from a safe room would significantly reduce the risks and costs, benefiting all stakeholders. Furthermore, as we move towards remotely controlled and autonomous ships, t is obvious that the pilot's role will evolve toward remote advising and management. There is no sense in a pilot physically boarding a ship that is remotely controlled from the shore or that sails autonomously.

Despite technological advancements, the legal framework governing the work of maritime pilots has barely changed since the first regulation in 1854. Regulation of the work of maritime pilots, apart from safety recommendations, has remained at the level of national states or even lower. Consequently, we have thousands of legal frameworks worldwide today. Although countries can regulate remote piloting through national legislation, as Finland has done, this cannot be a long-term solution and can only assist certain segments of navigation.

The current situation with remote piloting is reminiscent of the early days of the introduction of radio communication on ships. Ships began to install radio stations at the beginning of the 20th century, but until the issues of frequency allocation for distress assistance, standardized signals, and communication protocols were resolved, general communication, particularly related to maritime safety, was not possible.

Today, as technology develops much faster, with remotely controlled ships already in use and autonomy advancing, there is a real danger that technological development will be hindered because the legal framework is not updated. Enabling remote piloting would not only reduce the risks and costs for the pilot but also be a step forward in the further development of remote ship control and autonomous navigation.

Technical and legal preconditions must be met for the introduction of remote technology. Therefore, it is necessary to introduce technical standards and provide a legal framework. With this type of pilotage, communication between the crew and the pilot must be flawless, and the ship and the pilotage area must meet all technical and technological prerequisites for the quality exchange of necessary information.

This type of piloting certainly represents the future; however, it brings major changes to the global maritime transport system. Primarily, it needs to be defined by the International Maritime Organization, then by organizations that introduce technical standards, and finally implemented into national legislation of different states to ensure pilot safety conditions.

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