THE JOURNAL OF NAVIGATION (2009), **62**, 427–437.
doi:10.1017/S0373463309005335 Printed in the United Kingdom

Shore-Based Pilotage: Pilot or Autopilot? Piloting as a Control Problem

Karl Bruno and Margareta Lützhöft

(*Chalmers University of Technology*)
(Email: margareta.lutzhoft@chalmers.se)

Remote, or shore-based, pilotage is an issue of some interest to the maritime community. When discussed, it is often in the context of new technology that in one way or the other is supposed to enhance piloting and enable ships to be piloted from the shore. This paper takes a different approach and instead looks at piloting as control of a complex system. Such an approach makes it possible to identify a fundamental problem with remote pilotage. The problem, along with possible solutions, is presented and discussed.

KEY WORDS

1. Control. 2. Maritime pilots. 3. Shore-based pilotage. 4. Navigational assistance.

1. INTRODUCTION. Remote pilotage is often discussed in the context of new technology that supposedly will revolutionize piloting and open up new and exciting possibilities for shore-based control of ships. This paper takes a different approach. By defining the act of piloting a vessel as control of a complex system, it is possible to shed new light on the role of the pilot and on the fundamental and technology-independent difficulties and possibilities of remote pilotage[1].

The concept of remote pilotage lacks a single, clear definition. The one perhaps seen most often (Hadley, 1999; Grundevik & Wilske, 2007) is the definition employed by EMPA[2] and IMPA[3], which states that:

> *[Remote pilotage is] 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.* (*Hadley, 1999, p. 3*)

Fundamentally then, remote pilotage is an act of pilotage, carried out by a licensed pilot, from a position that is not on board the ship that is subject to the pilotage. This is a service that to some extent is provided in several European ports – in the Netherlands, Belgium, Germany, France, Italy and Malta (Koester et al., 2007) – when

[1] Remote pilotage and shore-based pilotage are used interchangeably throughout this paper; the term 'pilot' is applied both to the pilot working onboard a ship and to the shore-based operator carrying out the remote pilotage.
[2] European Maritime Pilots' Association.
[3] International Maritime Pilots' Association.

the weather conditions are severe enough to prevent pilots from boarding at the regular boarding point. Under such circumstances, certain ships might be remotely guided to calmer waters – where a pilot can board – with the aid of radio instructions from a shore-based pilot, who uses radar to monitor the progress of the ship. The service is only offered to ships that fulfil certain requirements on length and draft, and the master, the pilot and the port authority must all agree that the remote pilotage can be carried out safely. This service is not offered as a replacement for regular piloting. Rather, it is a backup solution used only when the alternative is that the ship awaits better weather.

There are however reasons why it might be interesting to expand the idea. It is getting harder for maritime authorities to recruit pilots, and both ports and shipping companies perceive a possibility of financial gain with remote pilotage (Hadley, 1999). But it is self-evident that it is not a trivial question to move the pilot away from the bridge and into a control room ashore. The difficulties and the possibilities with such a change must be analyzed carefully, and the study presented here offers a contribution to such an analysis. By applying a control perspective to the act of piloting, a central but often overlooked issue becomes apparent. Here, that issue will be presented and some solutions will be sketched.

Piloting can be split into sea piloting, which refers to navigation in fairways, and harbour piloting, which refers to the manoeuvring of the ship in the harbour area (Norros, 2004). Such a division is in line with previous studies (Norros, 2004; Nilsson, 2007) and can be motivated by the fact that sea piloting and harbour piloting are two quite different tasks, with different requirements. In this study, only sea piloting was considered and, in the paper, the word piloting should be understood as sea piloting unless otherwise specified.

The paper starts with a general introduction to the concept of control, followed by an application of theories of control to the piloting domain. After that, an empirical study that was carried out to further explore the subject is presented, followed by a suggestion of several possible ways to mitigate control problems in remote pilotage. The paper ends with a discussion and with the conclusions of the study.

2. BACKGROUND.

Control is a concept used in many disciplines and with vastly different meanings. We will follow how it is applied within Cognitive Systems Engineering (which in turn closely follows how the concept is understood within cybernetic theories), a discipline concerned with the design and analysis of complex socio-technical systems, i.e. systems consisting of both human operators and technical artefacts. As Cognitive Systems Engineering deals – among other things – with control of such socio-technical systems, the term 'system' will be used throughout the paper. Unless otherwise specified, it can be assumed that the system in question consists of a ship that is controlled by its crew and a pilot.

According to theories in cybernetics and Cognitive Systems Engineering, control is a situation where a controlling system (a controller) keeps the output from a controlled system within a specified performance envelope (Ashby, 1956). A simple example is a thermostat attached to a radiator. Such a thermostat is normally controlling the ambient temperature, trying to maintain the temperature setting. If the temperature rises, the radiator is switched off, and if the temperature decreases, the radiator is turned back on again. This is known as feedback-driven control; control performed on the basis of input from the environment (Johansson, 2005).

Another type of control is feedforward-driven control. If the controlling system has a good enough model of the controlled system, it is in theory possible to compensate for deviations before they occur. If we imagine a computerized thermostat with an extensive database of prior temperatures in the room, periodical deviations – such as, for example, that the temperature generally rises after sunrise – can be anticipated and compensated for before they occur (Johansson, 2005). If it works as intended, this leads to more efficient control.

A different example, more closely related to the relevant domain, is the manoeuvring of a ship. If the control of a turn is solely feedback-driven, it will be difficult to come to the desired course because there is always a certain lag before the ship answers the helm. With feedforward-driven control, the helmsman can instead rely on his feeling for the ship's manoeuvrability to stop the turn at the right moment. Naturally, the success of feedforward-driven control in this case depends on how well the helmsman knows his ship. If he misjudges the situation, the control will be less effective.

The example illustrates that there are problems with both types of control. If control is based only on feedback, the controller will take action only if a deviation from the desired state occurs, and if control is based only on feedforward, the controller is unable to adjust his performance based on the actual state of the controlled system. It follows from this that the most efficient way to control any sort of complex process is through a combination of feedback and feedforward. (Hollnagel & Woods, 2005; Johansson, 2005.)

Hollnagel (2002) has proposed a simple model for human control known as the basic cyclical model of control. The model, shown in Figure 1, presupposes that the controller has a clear goal – a state of the controlled system that should be achieved and maintained. Based on its understanding of the controlled system – its *construct* – the controller takes action to achieve or maintain the desired state. This action produces a response which returns as feedback to the controller. This feedback (which, as noted by Johansson (2005) also can include external events that are not related to the controller's previous actions) modifies the controller's construct, which is then used as the basis for the next action.

Returning again to the manoeuvring example; the helmsman with the goal of steering his ship to a certain course uses his knowledge of the ship's manoeuvrability – his construct – to decide when to initiate the rudder action. The action then produces a response – the ship's rate of turn slows – which modifies the helmsman's construct, i.e. he notices how well the ship answers the helm. He can then use this updated construct to modify the rudder deflection if necessary[4].

3. PILOTING AS CONTROL.

The use of pilots – generally experienced mariners with a high degree of local knowledge – to assist ships with navigation in fairways and ports has a long tradition in seafaring. To safely take a ship into port

[4] It should be noted that the efficiency with which the construct can be modified largely depends on the quality of the initial construct. An experienced helmsman might be able to steer without very much feedback, but on the other hand, all the feedback in the world will not help a person with no concept at all of how to steer a ship.

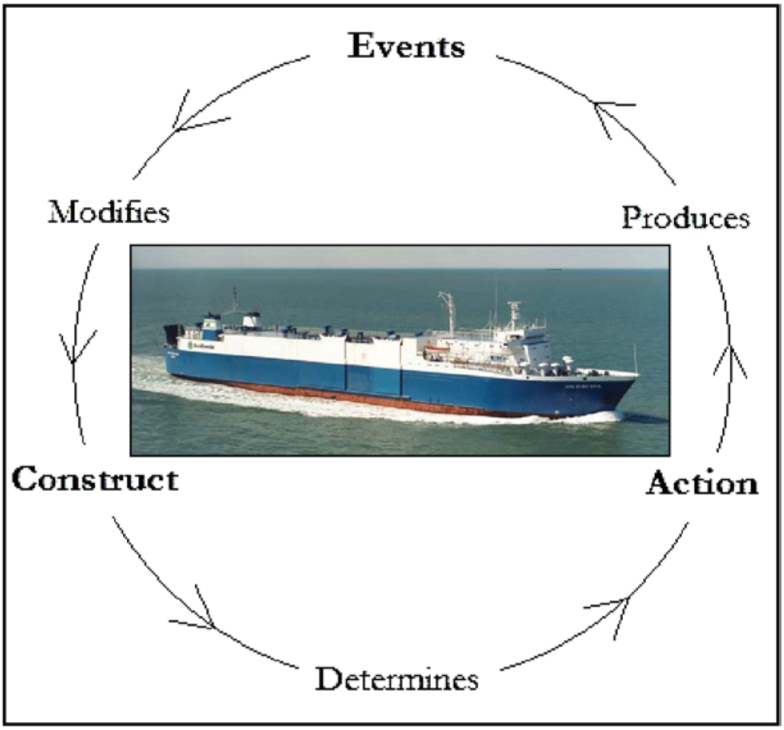

Figure 1. The basic cyclical model of control.

from the open sea is a challenging task that requires extensive knowledge of the local conditions. If a ship trades in many different ports, it is for obvious reasons impossible for the regular navigating officers to have such knowledge. Thus the need for pilots.

The control that is exercised by the pilot and the regular crew has a clear purpose – to keep the ship correctly positioned in the fairway at the correct time. This control is both feedback- and feedforward-driven. The pilot gets feedback from many different sources – the bridge instruments, the movements of the ship, the other people present on the bridge – but the primary source of feedback is visual feedback from the environment (van Westrenen, 1999). Feedforward-driven control is exercised through the pilot's local knowledge, which is used to plan ahead and to act without having to wait for feedback. From this perspective, the primary tasks of the pilot are to use the local knowledge of the fairway and of the local conditions to provide the foundations for the construct that enables feedforward control, and to make efficient use of the incoming feedback to update and modify that construct.

In a system where remote pilotage is employed, the situation is different. The most obvious difference is that such a system is controlled not only from the bridge but from a shore-based control room as well. The pilot, who is located in front of a display far from the ship, issues instructions to the crew on the bridge, who must manoeuvre the ship. The crew generally lack the local knowledge of the pilot, which makes it more difficult for them to form an effective construct and thus interferes with their ability to keep the ship at the right place at the right time. The pilot, on the other hand, only has access to feedback that is inferior to the feedback which is available on the bridge. Instead of direct visual and sensori-motoric feedback, the shore-based pilot is limited to the information that can be received via a computer screen (e.g., speed, rate of turn, course) and from radio communication with the ship. Such limitations on feedback also interfere with the ability to control the system.

These two effects of controlling the system from two places – a less effective construct for the crew and inferior feedback to the pilot – is the fundamental problem with any sort of remote pilotage. To put it differently: if everything else remains unchanged, remote pilotage will always lead to less efficient control of the system. This is a problem that must be managed in some way if remote pilotage is to be conducted safely.

4. EMPIRICAL STUDY.

To further explore the issue, an empirical study consisting of interviews with active pilots and Vessel Traffic Service (VTS) operators was conducted. The purpose of the study was to increase the understanding of how piloting is carried out today and what that implies from a control perspective.

4.1. *Method.* The interviews were performed using a focus group method. A focus group is essentially a form of group interview that collects information from several participants at once and at the same time makes use of the dynamics of a group discussion. The basic principle behind a focus group is that the participants are presented with a topic or with a set of topics and are encouraged to discuss these with one another. The discussion is led and controlled by a moderator (Millward, 2000).

Two focus groups were conducted as part of this study. The first had participants that were active pilots at the port of Göteborg, Sweden, as well as participants that worked with administrative duties at the Swedish Maritime Administration. Participants in the second focus group were VTS operators from Göteborg and administrative personnel. In both cases, there was first a preliminary discussion about terms and definitions related to remote pilotage, and then the main topic for the focus group was: "*What are the distinguishing features of successful ship assistance?*" The participants were encouraged to approach this question from their own perspective; the pilots from a ship-centric, piloting, perspective and the VTS operators from a shore-based perspective.

4.2. *Results.* The study generated large amounts of qualitative data. There were many interesting opinions expressed, though not every one was important from a control perspective. Here, the most relevant results will be summarized.

The most prominent result from the first focus group was the importance the pilots attribute to establishing good contact with the regular crew of the ship. It was considered to be a prerequisite for all successful piloting. This is well in line with the control perspective presented above. If the pilots are to use their local knowledge to provide the foundation for a well-functioning construct, they must first establish mutual trust with the crew. If the crew do not trust the pilot, they will obviously be unable to make use of his knowledge.

Another interesting result was that the pilots commented that good contact with the crew enabled the pilot to find his own role within the bridge team, and that this role was not always the role of navigational advisor. Rather, with a well-prepared crew, the pilot could end up in a more passive role, more supporting the crew's own decisions than helping to make them. This was supported by the VTS operators, who claimed that from their point of view a significant percentage of the ships trading in the port of Göteborg were so well equipped and had such competent crews that they would do just as well without a pilot onboard. In control terms, those crews can be considered to have a sufficiently well functioning construct even without the added local knowledge of the pilot.

A point discussed during both focus groups was that many of the regular crews lacked knowledge about the VTS system and the role of VTS – including knowledge of the training and competence of operators – and that this could lead to insecurity and a lack of trust. Partly on the same topic, the VTS operators believed that this lack of trust was in part related to the lack of standardized communication routines.

5. HOW TO HANDLE THE CONTROL PROBLEM?

The fundamental problem with remote pilotage from a control point-of-view is, as detailed above, that any system where the pilot is not onboard the ship he is piloting will be controlled less efficiently than a system with the pilot on the bridge. This does not mean that remote pilotage is an impossibility, but that the fundamental problem has to be managed in some way. This paper outlines four principal ways to do this, based on control theory and on the results from the empirical study:

- Restrictions on which ships that are allowed to use the service
- Provision of extra information to the ship's crews
- Improved feedback to the shore-based pilot
- Standardized procedures and communications routines

They will all be discussed below. It should be noted that an underlying assumption here is that the shore-based pilot will not assume all the tasks of the onboard pilot. Rather, today's tasks of the onboard pilot will be divided between the regular crew and the shore-based pilot. This is likely to be unavoidable, given that some tasks carried out by the onboard pilot are not easily separable from the bridge environment.

5.1. *Ship measures.* With a shore-based pilot, the crew of a ship lacks the immediate access to local knowledge that a pilot on the bridge can provide, which in turn makes it harder for them to form an effective construct and thus to exercise efficient control. This is to some extent true for all ships, but is the problem equally serious for all ships? No. There are four common conditions that determine the control characteristics of a system – time, knowledge, competence and resources (Hollnagel & Woods, 2005). Insufficient time, knowledge, competence or resources will all make the system harder to control and increase the risk of loss of control, and conversely, plenty of time, knowledge, competence and resources will make the system easier to control.

For the purposes of the current domain, the conditions can be said to roughly correspond to a ship's manoeuvrability (time – a ship with limited manoeuvrability has to be steered with more forward planning than a ship that is easy to manoeuvre), how well equipped the ship is (resources – primarily navigational equipment) and the crew's level of knowledge and competence.

The manoeuvrability of a ship is generally constant, as is the navigational equipment available onboard.[5] But the crew can be supported by providing them with extra information. This provides two ways in which the control problem in remote pilotage can be managed through ship-related measures – restrictions on the use of the service and provision of supporting information for the crew.

5.1.1. *Restrictions on use.* In ports where remote pilotage is available today, the service is offered to a relatively small segment of ships (note that this is the primary way in which the fundamental control problem is handled in those ports) and ship restrictions on the use of remote pilotage will remain a necessity. It is not possible to safely provide remote pilotage to all ships. The variation in equipment, manoeuvrability and crew competence are large and a number of ships will always require the assistance of an onboard pilot. However, as indicated in the empirical study presented above, there are also a number of ships that today are obliged to take a pilot even though they might not necessarily need one. These ships are the main target for remote pilotage.

Restrictions are in practice a way to guarantee that all ships that will use remote pilotage have an acceptable level of time, knowledge, competence and resources available. This means that the ship and its crew have at least some ability to exercise control on their own – and thus that the need for a pilot's assistance is less urgent.

5.1.2. *Information support.* Ship restrictions on the use of remote pilotage mean that only ships that meet certain requirements are able to utilize the service, which increases the possibilities of effective control. To further assist the onboard crew in the formation of a well-functioning construct, they can also be provided with information from the shore.

During normal piloting operations, the pilot will prepare a passage plan that includes courses and speeds to be followed from the boarding point to the port, as well as safe passing distances to hazards and other relevant information. One way to support the crew during remote pilotage would be to provide them with an extended version of this plan. It would include courses and speeds along with other relevant information for the passage – including information that might not be published anywhere but which is still known to be important by the pilot – and would be transmitted to the crew before entry into the fairway. There are several possible formats for such a plan. The simplest solution is a text-based plan with coordinates for the turning points, planned time for passage etc. Another option is to use a picture format with the route drawn on a chart. It would give a better overview of the plan and could be combined with the text format for the presentation of weather reports and other information that is not easily presented in a picture. It would also be possible to utilize a fully digital format, to be directly uploaded to the electronic charts aboard. This would however demand a high degree of technical standardization and would also mean that the crew would not have to work with the plan

[5] There are in fact various ways to enhance the navigational equipment of a ship through the use of portable products. Portable systems with electronic charts and AIS are regularly used by pilots today. However, these systems have to be transferred to the ship, and there is no easy way to do that unless a pilot brings them. From a remote pilotage point-of-view, the equipment of a ship can for the purpose of this analysis be considered constant.

themselves, something that likely would decrease their understanding and awareness of how the passage is planned.

Even an extended passage plan would not be equivalent to the information an onboard pilot can provide. Nevertheless, the provision of an extended passage plan together with restrictions on the use of a remote pilotage system will likely suffice to give the crews that actually utilize the system a foundation on which they may safely conduct the passage with the assistance of a remote pilot.

5.2. *Better quality feedback for the pilot*. For the shore-based pilot, the main control problem is the comparatively low quality of the available feedback on shore. Instead of direct visual feedback, the pilot has to work through a computer screen and instead of direct communication, radio telephony or similar must be employed. On-shore measures should thus focus on improving the access to, and the quality of, feedback for the pilot.

To provide the shore-based pilot with feedback that is qualitatively equivalent to the feedback available on the bridge is in every practical sense impossible. However, with existing technology it should be possible to achieve noticeable improvement compared to the simple radar-and-radio solutions that are the standard for remote pilotage today. The use of electronic charts – where the planned route of the piloted ship can be entered – together with AIS information allows for continuous monitoring of the position of the ship, in the fairway as well as relative to the planned course. Video cameras, as suggested by Grundevik & Wilske (2007), could also be employed to get direct visual feedback from parts of the fairway and the port. In many ports this is already available. For communication, VHF (Very High Frequency, used for maritime radio telephony) should suffice but must be supported by a backup system – the easiest probably being cellular phones.

Combined with the display system, it could also be possible to employ a dynamic predictor that would integrate available information about the ship's speed and course, wind, currents etc. to provide the anticipated position of the ship in for example 30 seconds or a minute. This would further strengthen the ability of the pilot to plan ahead in the short term and to discover potential problems early on, which is very important as loss of control is intimately linked to unexpected events (Hollnagel & Woods, 2005).

5.3. *Standardized procedures and communication routines.* It is not enough to separately support the crew's and the pilot's ability to exercise control. The cooperation and coordination between them must also work. This entails at least two issues. The principal issue is the establishment of standardized procedures for how remote pilotage should work. If everyone knows how things are supposed to happen, there is less need to coordinate and thus less risk of misunderstandings. Clear procedures are also a fundamental way to support the maintenance of control in any system (Hollnagel & Woods, 2005). Furthermore, standardized procedures could be a way to deal with possible mistrust between the crew and the shore-based operator.

The second issue is communication. Standardized communication protocols are necessary to deal with language differences and different language skills, and to handle the information that needs to be transmitted between the ship and the pilot. Today, the lack of clear communication routines are experienced as one of the main sources of trouble in the relationship between VTS operators and ship's crews, and it is likely that those problems will also plague a system with remote pilotage unless fixed routines are implemented.

6. DISCUSSION. As described above, the act of piloting, whether performed by an onboard pilot or a shore-based pilot, can be viewed as the control of a complex, sociotechnical system. This view makes apparent a fundamental control problem with remote pilotage. It can, however, be argued that the pilot has, or at least in certain circumstances can have, other roles in addition to a controlling one, and thus that there can be other fundamental problems with removing the pilot from the bridge. This view would seem to be supported by the empirical study, where the pilots explained that their roles differ depending on how well-prepared the crew are, from a "true" piloting role to a function where the pilot simply confirms the decisions made by the regular crew. The question then is: Will the removal of this supporting role from the bridge have serious consequences for the safety of the system?

Probably not. It should be considered that the supporting role has evolved in an environment where the pilot today is wholly or partly superfluous, but still has to be present. Even if the regular crews find comfort in a supporting pilot, the issue has to be viewed from a perspective where a pilot is present for all fairway passages, no matter what. That makes it hard to say anything about how much importance the regular crews really attach to this role. Or to put it differently, the fact that it is nice to have a supporting pilot on the bridge does not necessarily imply that it would be a problem if the pilot was absent.

Furthermore, there is another factor that should be considered, namely that the good contact and mutual trust between pilot and crew that is a prerequisite for this supporting role – and for any successful piloting – is not always established. Studies (Transportation Safety Board of Canada, 1995) have shown that communication and cooperation problems between masters and pilots are not unusual. An ongoing debate in Seaways also points to this issue. In such cases, it can be assumed that the pilot will have little positive influence on the work on the bridge. This further supports the idea that an onboard pilot does not always increase the safety level. It could even be argued that if a pilot is not needed to assist the regular crew with his knowledge of local navigation, it might have a negative safety impact to take a pilot because of the possibility that a pilot's presence on the bridge will lead to a negative working climate and thus to increased risk. It should be stressed that this does not mean that an onboard pilot is always a risk or a liability. It only means that it is not necessarily a good idea to introduce a pilot into a bridge team if the pilot is not needed as a navigational advisor.

The aviation-shipping analogy should also be considered because it often comes up when shore-based pilotage is discussed. The essence of the analogy, as it is sometimes used by proponents of remote pilotage, is that, seeing that air traffic operates successfully under ground-based control, it should also be possible to safely and efficiently control maritime traffic from the shore. Looking closer, there seems to be little substance to the analogy. A study made by the Swedish Maritime Administration (Österlund & Rosén, 2007) to examine whether experiences from aviation could be applied to shipping found that the domains had little of relevance in common. van Erve & Bonnor (2006) also discuss the issue and reach similar conclusions. The most significant difference is the much higher degree of global standardization within commercial aviation. Formal international standards govern the layout and design of airports and navigational procedures in aviation. A consequence of this is that flight crew generally do not need specific knowledge of local conditions[6]. In shipping, conversely, no two fairways are the same and local conditions vary significantly between ports. Furthermore, ships are of necessity navigated in much closer proximity to obstacles than are aircraft (Österlund & Rosén, 2007).

But even if the success of air traffic control says little about the prospects of remote pilotage, there are probably still things that can be learned from aviation. Österlund & Rosén (2007) point out that there might be things to learn from air traffic control when it comes to for example the development of more sophisticated VTS solutions or – presumably – the development of remote pilotage. Two of the main problems identified in the present empirical study – the possible lack of trust between ships and VTS operators and the lack of standardized communication routines – are not serious issues in aviation. Communication and establishment of trust between air traffic controllers and flight crews work well, and it is possible that the methods used in aviation to achieve this could also be put to use in the maritime domain. It is an issue that deserves further investigation.

The final point of discussion is the degree of significance of the control problem with remote pilotage that this paper introduces. The position presented here is that the problem is fundamental and unavoidable. This means that, regardless of any possible technological advances, it will never be possible to simply replace an onboard pilot with a shore-based pilot while maintaining the same level of safety in the system. The control problem has to be mitigated in any implementation of remote pilotage. Awareness of this increases the possibility of working out good solutions, and generally enables a more realistic understanding of what remote pilotage is and what it can be.

7. CONCLUSIONS.

This paper is based on the conviction that the issue of remote pilotage is best discussed not in the context of technology drivers but in the context of control. By defining piloting as control of a complex system, fundamental and technology-independent problems become apparent and these problems have to be mitigated in any implementation of remote pilotage. The more extensive the implementation, the more mitigation is needed. In the paper, an outline of possible solutions based on control theory and an empirical study has been presented. These are most likely not the only ways to support control in a remote pilotage setting; further research is needed to fully explore the consequences of the problem and its solutions. In this further research, it is also important to include the users of the system, that is, the ships and the crews that are subject to piloting.

What the reasoning presented here aspires to do is provide new insight, not only into the issues involved in remote pilotage, but into the act of piloting itself, whether ship- or shore-based. Furthermore, we attempt to identify and define a central problem with shore-based pilotage. It is common knowledge, and good research practice, that before a problem can be solved, it needs to be clearly defined. This paper aims to be a first step towards such a definition.

[6] A few particularly challenging airports across the world do require special familiarization training; these are however the exception rather than the norm.

ACKNOWLEDGEMENTS

We gratefully acknowledge the assistance of our participants and the Nautical Institute members. We also acknowledge the cooperation with and financial support of The Swedish Maritime Administration and the financial support of Region Västra Götaland.

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