

# Fairway Navigation – Observing Safety-Related Performance in a Bridge Simulator

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**ABSTRACT:** This paper proposes an approach of measuring navigation performance using a full mission bridge simulator. The motivation for this research is the updates in equipment and that the desire of using new instruments and technology not always is accompanied by analyses of the impact of the changes. The task of navigating in a fairway is proposed to be assessed through various methods to answer questions related to performance and the experience of using bridge equipment. The overall aim is to reach a higher degree of understanding and knowledge through the testing of different instrumentation setups.

## 1 INTRODUCTION

The equipping of a ship bridge has during the last decades changed substantially. One reason for this is the development of instruments such as for instance the Global Positioning System (GPS), electronic charts systems and the Automatic Identification System (AIS). This development in combination with an eagerness to adopt new technology and incorporate it into ship bridge systems contributes to the vast variety of instruments and systems on a ship bridge. Governments and companies are naturally from a safety and efficiency perspective interested in using new technology. An investigation of piloting in Sweden was started by the Swedish Ministry of Enterprise, Energy and Communications in December 2006. The overall aim of this investigation is to review the possibilities of using new technology. One issue to be investigated is “shore-based pilotage” and whether piloting with the help of new technology could be more efficient through support from a shore-based central.

As shown in an earlier study of the accident involving the ship “Royal Majesty” (Lützhöft, 2002) new technology is not necessary equivalent to higher safety. It depends on how well the operators know the technology and its constraints. Some radar training instructors identified new behaviors during simulator training which violated existing rules for navigation (Lee et al., 1993). These violations were believed to be triggered by the experienced reliability of the new equipment.

The seafarer is remarkable at adjusting to new circumstances (Lützhöft, 2004). In this context Lützhöft discussed the positioning of equipment on a ship bridge. On a traditional bridge, where all the equipment is placed in one row, and where new equipment has been added after years of sailing, it is not unusual to find complemented equipment (like for instance an Electronic Chart System) placed where there was room for it, usually far at one end. This could be compared to a modern cockpit bridge design where the Electronic Chart System has a central position in the bridge layout.

A study of pilots in Finnish coastal waters (Norros, 2005) showed that personal piloting style affects the way that the piloting task is solved more than the available technology at the ship bridge. This indicates that a key factor which has to be taken into account is the way the equipment is used.

In order to understand how new technology affects navigational performance in fairways, it is essential to gain more knowledge of how the ship is navigated.

## 2 THE PROBLEM

Taking a ship to and from a berth always involves some safety risk. According to Boisson maritime safety is both the material state resulting from the absence of exposure to danger, and the organization of factors intended to create or perpetuate such a situation” (Boisson, 1999, p. 31).

The Swedish Ministry of Enterprise, Energy and Communications wishes to know how new technology can be used to facilitate piloting and make it more efficient. The ministry also wants to know what the prerequisites for developing “shore-based pilotage” are.

In order to know more about how new technology can be used in the future, our aim is to learn more about how work is performed at present and what the prerequisites for carrying out the task are. One way to gain more knowledge is to compare two sets of equipments that are presently available on a ship bridge which reflect differences due to the changes in technology that have already taken place.

Questions raised include: How is the work experienced on the ship bridges with existing technology? Are there any differences in experience and performance due to differences in equipment standard? More specifically, we want to:

1. Measure the experience of workload related to two different sets of equipment.
2. Compare the experienced feelings related to the work situation.
3. Compare the performance in the task of navigation in fairways related to sea safety.

We are also interested in analyzing the performance on the bridge to find if there are any salient navigation strategies that are manifested in one or both of the tested work environments.

### 3 METHOD

We suggest that learning more about the work on a ship bridge can be obtained through studies of work in a full mission bridge simulator. “Full mission” means that the environment where the navigation task is simulated is authentic in comparison to equipment that could be found on an operating ship.

#### 3.1 *The value of simulator studies*

As long as the tasks are realistic and the performance can be analyzed so that it is possible to separate its determinants, simulator studies are valuable. Funke (1988), who used simulations to study complex problem solving, stressed that “it should be analyzed how participation in simulation affects problem solving in ‘real’ life problem situations” (p. 297). For instance, many cruise companies stress that the use of navigation simulators in training is a way to enhance performance. Navigating a ship is basically a dynamic decision making task. According to

Brehmer (1999, p 10) such tasks have three important characteristics:”

- They require a series of interdependent decisions;
- The state of the task changes, both autonomously and as a consequence of the decision makers actions;
- The decisions have to be made in real time.”

These characteristics of ship navigation can be re-created and evaluated in a full-mission simulator by having participants solving tasks that are realistic, representative and carefully designed.

#### 3.2 *Tasks*

The task of navigation can differ depending on the ship, e.g., factors like size and propulsion capacity, and the area, e.g., the water to be navigated. Normally out in the open sea there is no need for piloting. When modeling the pilot task, Norros (2004) divided piloting into two different types of piloting called sea piloting and harbor piloting. Sea piloting refers to the navigation through the archipelago and/or fairways, and harbour piloting refers to the “maneuvering of the ship in the harbour area” (p. 186). Based on the special interest in piloting from the Swedish Government, the focus of this research will be *navigating in fairways*, comparable to the one Norros refers to as sea piloting. In the simulator participants will be asked to solve navigation tasks in confined waters.

#### 3.3 *Understanding and creating the task*

In order to create an understanding of the task to be studied and lay a foundation for the creation of the scenarios, a Hierarchical Task Analysis (HTA) was conducted. The HTA was based on interviews with four experts, fully authorized marine pilots, lasting approximately 2 hours each. Of the four experts interviewed three are still working as pilots. The interviews were conducted at two different locations at various times of the day. Pilots were chosen for this part of the interview because they naturally and frequently change ships in their work. This gives them experience of various types of ships which was considered as favorable. When the task of navigation in fairways was decomposed to a satisfying level, the work of finding problems related to the task began.

With the HTA functioning as a foundation, instructors at a maritime university and active captains were interviewed. This time the focus was on the perspective of the captain in piloting situations. Discrepancies in communications between pilot and captain have been found in some studies.

In total, four captains in active duty and two instructors were interviewed. Of these, two captains and two instructors were interviewed in a group and two captains individually. The interviews lasted approximately two hours.

The results from the HTA and the problem interviews served as a foundation for creating representative scenarios for the tests in the simulator.

### 3.4 The test setting and participants

Two configurations of bridge types were chosen. One setting called “traditional bridge” consists of less advanced technology. The second bridge is an advanced bridge with an Integrated Navigation System (INS). Both bridge types will follow regulations regarding what equipment that is required. In table 1 the most evident differences are presented.

Table 1. Major differences between the bridge types

Traditional bridge	Integrated Navigation Bridge
Paper Chart	Electronic Chart System, although paper chart available
Automatic Information System through a Minimum Keyboard Display	Automatic Information System integrated with the Electronic Chart System and/or Radar
Basic function on autopilot, no function like “curved headline”	Advanced autopilot with the function “curved headline”
No conning display, but information available elsewhere	Conning display
Requirements to plot position in paper chart	No requirement to plot position in paper chart
	Possibilities to overlay information systems like Electronic Chars System and Radar

We plan to test 28 bridge crews consisting of two members each. Each bridge crew will conduct test scenarios on both ship-bridges. This is exemplified in table 2 where two scenario trials for two bridge crews,  $\alpha$  and  $\beta$ , is exemplified.

Table 2. Participation over time for two different bridge teams

Bridge Team	Participation order	Bridge Type	Scenario
$\alpha$	1	Traditional Bridge	A
$\alpha$	2	INS Bridge	B
$\beta$	1	INS Bridge	A
$\beta$	2	Traditional Bridge	B

The route will be preplanned and each team will have time to familiarize themselves with the route.

The task is to navigate the ship according to the route plan as fast as possible with maintained safety. Two pilot studies have been conducted in which both settings and scenarios were tested. Two active captains and three cadets, soon to be 2nd officers, tested the scenarios and bridge settings. The response was that the scenarios were realistic and that they were equal in difficulty. Although perhaps not all the events could be expected to be encountered on one passage, the response to the pilot studies were positive.

Participants for the study are being recruited among active captains and cadets in their final year, soon to be 2nd officers.

## 4 WHAT TO MEASURE, WHY AND HOW?

### 4.1 Risk and Sea Safety

Recommendations from the *bridge procedures guide* and STCW regulations will play a central part for the assessment of work performance on the ship bridge. This assessment will be done by experts.

### 4.2 Performance

During the voyage the route will be registered so that it will be possible to compare the planned route with the performed one. A debriefing session will be held after each trial, during which reasoning about deviations from the planned route regarding for instance speed and heading will be discussed.

Judging performance related to sea safety is a complex matter. In some studies Cross Track Error (XTE) has been used as an indicator of performance. We argue that XTE in our case is less accurate from the perspective of sea safety. To follow a planned route in detail is not necessarily safer than to deviate for safety reasons, therefore we consider it unrealistic to ask the captains to focus on staying on the track as the main task. It could lead to participants not navigating as they would usually do, in order to try to stay on track. Instead we use experts to rate each bridge teams’ performance according to existing rules and procedures. A safety margin will however be assessed at a number of given points.

We will register average speed since it is valuable to use the speed to assess sea safety.

It is interesting to measure Closest Point of Approach (CPA) in some cases. CPA is also a measure that has to be dealt with carefully to not overestimate potential danger. A ship can pass another ship by the stern with a relatively small CPA and still have acted in a safe manner. The same CPA could be more dangerous if the ship was passed on the bow.

### 4.3 Workload through heart rate

Heart Rate Variability has been used to measure mental workload as “variability is generally found to decrease as the load increases” (Wickens, 2000, p.465). In aviation research, tests have been conducted to compare reactions in the real world with reactions in simulators (Magnusson, 2002). The results indicate that the psychophysiological reaction patterns for the two settings are very similar. We expect to attain a good measure of mental workload at the ship bridge through measurements of HRV.

### 4.4 Subjective measures

We will use three subjective measures to collect information regarding participants’ experience of the work setting.

#### 4.4.1 Subjective Task Load

We will use the NASA Task Load Index (TLX) as a self-reporting method for assessing workload, both physical and mental. When using TLX, workload is defined as the “cost incurred by human operators to achieve a specific level of performance” (Gawron, 2000, p.130). We are interested in measuring workload that is experienced during the task. This can be used as a control of the scenarios as it will provide information regarding the workload experienced in the bridge settings. The participants will be asked to rate the task on six different dimensions after having performed the tasks in the simulator.

#### 4.4.2 Affective responses

The Swedish Core Affect Scale (SCAS) is a method which is used as a self-report measure of core affects. It measures core affects which are “cognitively accessible elements of a current mood” (Västfjäll, Friman, Gärling & Kleiner, 2002, p.19). This means that measurements from the same individual can differ depending on the current mood. In our study participants will assess their mood on two dimensions immediately before and after the task solving in the simulator. The two dimensions are *valence* and *activation*. “The valence dimension is interpreted as reflecting the degree of affect that provides information about the current well-being [...] activation, refers to subjective experience of energy or mobilization” (Västfjäll et al., 2002, p.20). An earlier study shows that the adjective ratings are “reliable measures of the independent valence and activation dimensions proposed” (Västfjäll et al., 2002, p.19). It has also been shown that SCAS has a

positive correlation with Heart Rate Variability. In this study we will analyze self reports of core affects to see if there are any differences in the experience of using the two bridge types.

#### 4.4.3 Experience of control

From a Joint Cognitive System point of view (Hollnagel, 2005) both the bridge crew and the bridge equipment are constituents of the system that we will study.

The participants will answer a question about their perceived degree of control at regular intervals along the scenarios. When answering the question they will describe their experience of the situation as a whole and thus the experience of working in the system. By doing this it will be possible to compare the experience of working at the two bridge systems as a whole.

## 5 EXPECTED FINDINGS

### 5.1 Comparing new and old technology

We expect the results to provide information on the impact of changing bridge equipment, and how the workload on the ship bridge is experienced. We will also learn more about how information is handled and what kind of information that is represented in a good way and gain clues to which information representation can be enhanced.

### 5.2 Data

We expect the following data to be accessible:

1. Video recordings. The work with the electronic equipment like radar and ENC (Electronic Navigation Chart) will be recorded.
2. Expert evaluations of each scenario trial
3. Independent performance measures such as:
  - Time (average speed)
  - Measures of relevant safety margin
  - Measures of relevant CPA
4. Heart Rate (HRV)
5. Experienced work load (NASA TLX)
6. Experienced core affect (SCAS)
7. Experienced control during the scenario trials

These data will serve as a foundation for comparing the two bridge settings. We intend to identify and analyse any salient work strategies. These will be compared to recommendations from a risk perspective.

## 6 LIMITATIONS

The task solving in navigating a ship is complex and dynamic. This study will be based on observations of performance in a simulator and although we have argued for the realism in the scenarios, there will always be doubts regarding the possibility of generalising our results. We will make the scenarios as realistic as possible but of course some constraints that appear unnatural may still have an effect. One example is the time. The scenarios will last for approximately one hour. In reality the legs of sailing are often longer. At the same time the number of critical events is much more frequent than they would be naturally.

The models used will have some constraints, as we rely on the functioning of the technology used, and factors like for instance how well the ship model is programmed and interacts with the imaginary sea can have an effect. The feeling of “this is not for real anyway” may be present to some degree. Related to the dynamics of the task one could always question the possibility of generalising results. However, in a simulator we are able to describe the prerequisite for the scenarios in detail, and play back the recordings, and thus learn something from these situations.

We have a limited opportunity for choosing participants. In this study active captains and advanced cadets have been invited to participate. This may lead to a positive selection. Thus, our sample may overrepresent participants with a special interest for this kind of work or for knowledge of the simulator itself.

## 7 CONCLUSIONS

We have primarily set out to learn more of the solving of the task of navigation in fairway performed at a ship bridge. Our measurements will cover both user perspective and performance related to the joint cognitive system. With this diversity of measurements we believe we have a good opportunity to increase the knowledge base regarding possibilities and constraints of new technology.

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