

THE USE OF LINKED SIMULATORS IN PROJECT “HORIZON”: RESEARCH INTO SEAFARER FATIGUE



Professor Mike Barnett
Warsash Maritime Academy

Mike Barnett is Professor of Maritime Safety and Head of Maritime Research at Warsash Maritime Academy. After a seafaring career, Mike joined Warsash in 1985 as a lecturer in tanker safety. He has been Head of Research since 1991, during which time he has directed many externally funded research projects in areas relating to maritime human resources. Mike is an external examiner for two UK maritime universities and also contributes to a number of national and international industrial working groups on the human element.



Ms Claire Pekcan
Warsash Maritime Academy

Claire Pekcan is a Senior Lecturer at Warsash Maritime Academy, UK. She holds an MSc in Occupational/ Industrial Psychology and her principal role is teaching applied psychology to seafarers, across the maritime curriculum, from bachelor degrees to resource management and leadership courses. Claire is also the course leader for the Academy’s ground-breaking distance learning MSc in Shipping Operations delivered over the internet to an international cohort of seafarers. She is currently conducting research towards a PhD at Birkbeck College, London in the psychological contracts between seafarers and their employers.

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Barnett, M.L., Pekcan, C.H., and Gatfield, D.I. *Warsash Maritime Academy, Warsash, United Kingdom*

1 Introduction

Project “HORIZON” is a Framework 7 European funded research study to investigate the effects of fatigue on the cognitive performance of ships’ watch keeping officers, using a range of linked simulators and under different watch patterns and conditions of workload. The main partners in the project come from the UK, France, and Sweden and an international industry panel of stakeholders has also been involved to provide advice to the research team. The project, which received funding of over 4 million Euros, began in June 2009 and was completed in January 2012, when the final results were delivered.

The simulator-based experiments were focussed on two different watch patterns – the conventional 4 hours on, and 8 hours off regime, and the more arduous 6 on and 6 off watch pattern. A total of 90 officers undertook the experiments on both simulator sites at Chalmers University in Sweden and at the Warsash Maritime Academy in the UK. Chalmers University conducted experiments on the 4 on and 8 off watch with 30 participants, and a further 20 subjects undertook a “disturbed” 6 on 6 off watch regime, in which the volunteers missed one sleep period while undertaking extra duties.

Meanwhile, the experiments at Warsash studied an undisturbed 6 on and 6 off regime, in which participants undertook their watch keeping duties without any deliberate disturbance of their off watch rest periods. At Warsash, 10 identical simulator-based “voyages” took place during 2010-2011, involving 40 watch keepers (20 deck officers and 20 engineers) in linked bridge, engine room and cargo simulators. The participants undertook normal watch keeping duties for the 7 day “voyage”, and during that period, measurements were taken of their watch keeping performance and their levels of alertness, including the use of EEG recording.

This paper describes the scenario used in the Warsash experiment, the participants in the study, the measurements used, and some initial findings which are emerging from the project. It is hoped that the results will make a contribution to the mitigation of fatigue, not only for seafarers, but also to all of those operators who work on shift patterns and experience disturbances to their normal sleep patterns. In addition, the authors consider that this research project has demonstrated the value of simulators for scientific research.

2 The Research Design – the “Voyage”

The detail of the voyage route was designed by the research team and the relevant simulator instructors, and was conducted in exactly the same way during the ten sessions. The voyage was constructed to mimic a real voyage in the English Channel, including port visits and cargo operations, standard engineering watch keeping tasks, navigation and collision avoidance situations, mandatory radio reporting points, etc. (see Figure 1).

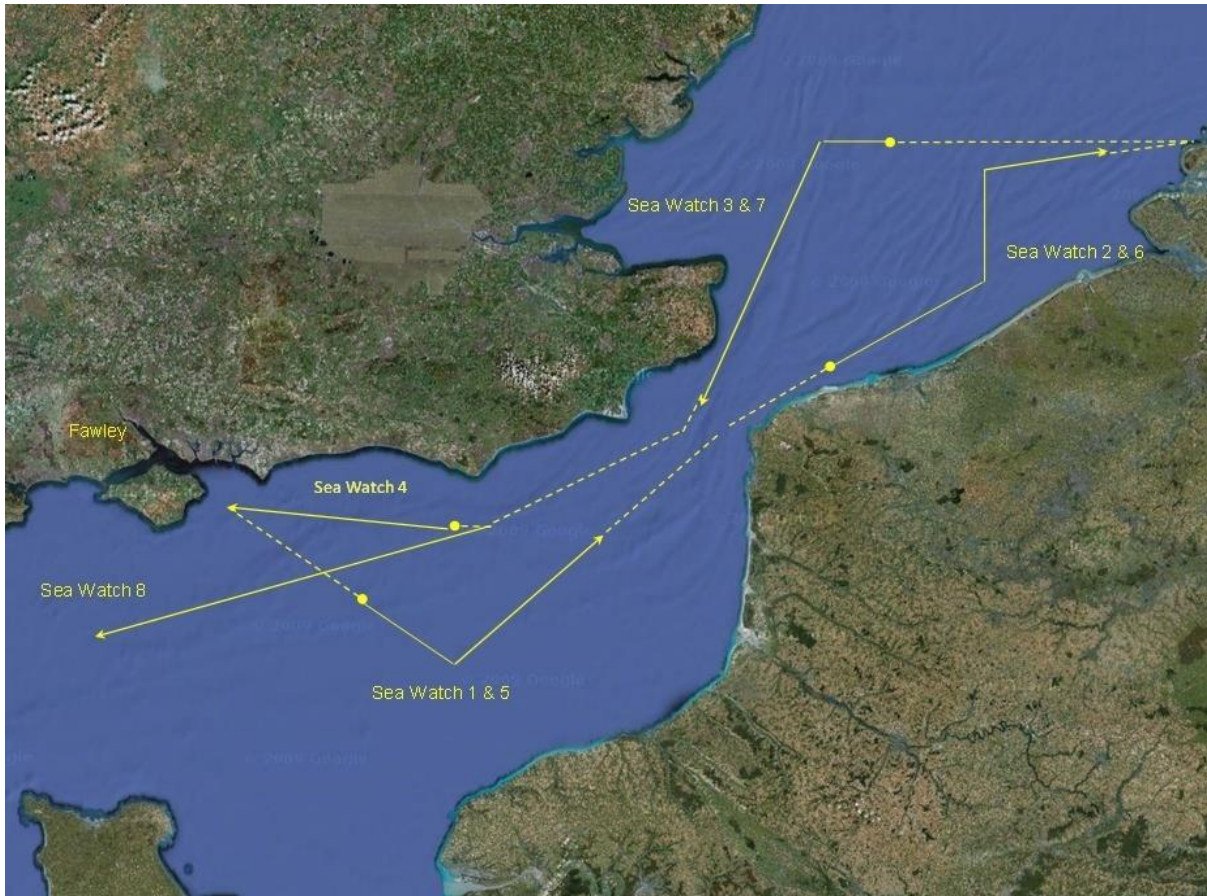


Figure 1: The simulated voyage between Fawley and Rotterdam

The voyage between Fawley and Rotterdam was repeated twice in seven days, and many of the events the participants experienced were also repeated, sometimes because they were normal routine activities, and sometimes in a disguised form. For example, each participant experienced two loads, two discharges and four transits of the Dover Strait. This meant that a comparison could be made directly between the measurements made in the first half of the week, with those taken during the second half. On the bridge, an identical amount of traffic was set for each run and was considered realistic for the waters involved. It varied in intensity from light to relatively heavy traffic. Given a maximum vessel speed of less than 14 knots, the maximum distance per watch was around 85 NM in a 6/6 watch. In the engine room, the normal watch keeping duties were performed under identical circumstances for each of the ten runs.

The watch system was the traditional 6 hours on and 6 hours off system, without deliberate disturbances off watch, but with a change: a bridge participant in one watch team did not continue from where the participant before had finished. The bridge simulator was re-set at the same point at the start of the previous watch, and the second watch keeper did the same part of the voyage again. The bridge watch keepers handed their watch over to one of the staff, and received their watch in a similar way, thus they did not meet each other at all at this time, in order to avoid an exchange of information on the geographical position of the vessel. This did not affect the engineers in the same way, as the nature of their duties has no geographical context, but is a continuous process. This method had a number of advantages, most importantly, the ability to directly compare the same watch keeping conditions shifted by 6 hours.

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A number of considerations influenced this research design, and the choice of route and event timings. The main considerations were:

- Because the distance sailed in one watch period was not exactly predictable, the start position of one watch would not be the same, unless the simulator positions were re-set each watch thus giving identical conditions to each watch keeper.
- The application of EEG electrodes took up to 40 minutes of the watch time. The cognitive tests took approximately 5 minutes for each test, and therefore, the ability to hand over the watch to the staff saved valuable time.
- The watch hand over to and from the staff, and not to and from each other, also had the benefit of allowing observation of the participants at close quarters, so that assessments of their sleepiness levels and performance at these critical times could be made. In the light of the “*Shen Neng1*” case (ATSB 2010) where the omissions at the watch handover were contributory factors, this provided valuable information
- At the ship’s normal full speed, the ports of Fawley and Rotterdam are about 24 hours apart. Two port visits in Fawley (Days 1 and 5) and two more in Europort (Day 3 and 6) were scheduled. Cargo operations took place during each port visit.
- No tidal conditions were used, thus avoiding the use of tide tables and times; hence all participants were exposed to the same situations.
- Real time matched the time displayed in the simulated view from the bridge, and hence the levels of daylight in the simulator were adjusted to be identical to those outside.
- The weather conditions were consistent and benign; some reduced visibility was encountered mid-week. Traffic was realistic for the area and a basic voyage plan was given to the participants during the familiarisation period on the first day loading in Fawley.

The voyage scenario was constructed carefully to ensure a high level of realism. Performance evaluation took place on every watch. Events during the voyage scenario were classified into normal, communication, special and unplanned events. Normal events (or situations) were those which a seafarer on a similar sized vessel would typically encounter during a voyage in the English Channel, but without highly safety-critical or abnormal emergency situations.

These normal events were, for example:

- Keeping the vessel's logbook (diary): participants were expected to keep the ship's log book, which is provided for each bridge, engine and cargo control room;
- Marking ship’s positions on the chart: participants were required to mark the vessel’s position on the relevant chart, according to the Master standing orders.
- Watch handovers: participants were given standing orders to exchange information with the next watch keeper or receive the watch from the previous watch keeper (which was a simulator instructor in both cases). Important events which occurred during the watch were reported.
- Since the route in the English Channel had high traffic density, it was likely that several close encounters with other ships would occur. Some of these were designed to be close encounters, and were recorded and evaluated by the instructor.

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- Similar normal watch keeping tasks, such as monitoring the performance of the main engine during the watch, and the status of the cargo systems were conducted in the engine and cargo control room simulators, and assessed by the instructors.

The communication events were, for example:

- Internal communications: there were situations when the participants were expected to communicate with the Master, Chief Engineer, or Chief Officer, depending on the simulator.
- The bridge OOW was called by a VTS operator and required to give a position report.
- Standard communication with outside agencies, e.g. other vessels, pilot stations or coastguards, for example, a report to Maas Pilots, and at the arrival off Nab Tower.

The special events were designed to elicit specific behaviours for scoring performance change over the week, for example, on the bridge:

- A waypoint with a potential collision avoidance situation involving an early alteration of course.
- A Gyrocompass error
- A vessel crossing from the port side, which does not alter course as per the COLREGS.
- A man overboard incident occurring on another vessel in the vicinity.

Unplanned events were those where a direct action by the participant might lead to an impact on other watch keepers, for example, a blackout in the engine room impacting on cargo operations, or a “near-miss” situation on the bridge.

Similar events were designed for both engineering and cargo control tasks. The participants were then scored by the research staff on their performance on all these tasks. These scores were recorded on a database and provided the basis for assessing the overall performance of each individual participant during the week.

Two other “rules” governed the running of the scenarios. These were:

- 1 No groundings or actual collisions were allowed. If this was likely to occur, the “Master” would appear on the bridge to avert a disaster. “Near-misses” were allowed. In a similar way, in the engine room, “black-outs” were allowed, but not catastrophic failures.
- 2 No participant was allowed to sleep on watch for more than five minutes. This was to avoid refreshing sleep to occur during working hours, thus contaminating the results.

3 The Linked Simulators

Warsash Maritime Academy used its newest Bridge Simulator, produced by Kongsberg, for these experiments. It is equipped with standard equipment found on modern vessels. The instrumentation comprises GPS, Radar with ARPA, Autopilot, VHF radio, intercom, etc. The outside view is simulated with screens, and three displays show conning and radar. The simulator is monitored centrally from an instructor room, where the Bridge is controlled by its own set of computers. The simulation runs were recorded by dedicated logging software.

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Radio and internal communication ("intercom") between participants and the Master, or engine room, or participants and other ships, was not recorded. However, participants were monitored via an internal CCTV system, with two camera positions, one of which was recording throughout bridge use.

The simulated vessel in the cargo simulator (LICOS) was a larger tanker than the bridge model (the M/V NORSEMAN, a double hull product carrier of 36,000 DWT). The choice of this vessel came from the necessity to avoid complex cargo operations. It was considered that the straightforward operation of the chosen tanker put all participants, who all had some experience in liquid cargo handling, at a similar level of ease of operation for the purposes of scoring performance. Six simulator stations are normally available for training, and these are situated in one large lecture room, but for the HORIZON experiment, only one work station was used. Each station has 2 screens, and is controlled individually from the instructor station. All participants had a five hour familiarization with the cargo simulator before starting the actual experimental run. Participants also had the ship's cargo operation handbook in written form for further guidance. The instructor simulated a variety of roles, for example, jetty and terminal officers. Each participant used the same work station, and under the same conditions, as well as the same scenario.

The model used in the Machinery Space Simulator (MSS) was a slow speed diesel engine and therefore matched both bridge and LICOS simulators without difficulty. The simulator consists of a Machinery Control Room with a control desk (MECD), switchboard and shaft generator breaker cabinet. The ships electrical system is comprised of two diesel driven alternators and one steam turbo alternator producing 60HZ and three phase 440 volts supply. An emergency diesel alternator complying with SOLAS requirements is also included within the system. The electrical system is fitted with the associated instrumentation and protective equipment.

It was recognised at an early stage in the design process that there had to be a trade-off between voyage realism and experimental control. Control is important for obtaining valid and reliable data without variability which cannot be accounted for. A number of measures assured an adequate level of realism, without losing control of the scenarios and events:

- 1 All the participants were practising seafarers, except one qualified Chief Engineer, who was a shore-based Engineering manager at the time of the experiments. All participants had experience on the type of ship simulated, and this may have contributed to creating a work condition similar to reality.
- 2 Sleeping quarters were located in a building called "Hamblemeads", just a few minutes walking distance from the simulators and the mess room. Both the cabins and mess room were similar to such quarters on board ship.
- 3 All simulator instructors and most researchers were ex-seafarers, and this may have added to the sensation of being "at work". In the simulators, the instructors acted as Master, bosun, lookout, pilot, able seamen, etc., as required and kept in role, even when participants were encountered off watch.
- 4 Master's and Chief Engineer's standing orders were available, and had to be signed as read and understood. A bridge lookout was always available, but in the form of an instructor who could be contacted via radio. The ship's log had to be completed for each watch, and was a standard logbook (in English language). In the engine room, a motorman was also available and similar logs were kept. In LICOS, radio contact was present for ship to terminal communication. Vital communication with the participants working in the Engine Room Simulator was maintained at all time. Logs that needed to

be filled in corresponded to standard logs used during liquid cargo handling. Watch changeover procedures mimicked those in a real vessel.

4 The Participants

A total of forty participants took part in the experiments. These were from different nationalities, including UK, Polish, Indian and Nigerian officers. A low prevalence of female participants in the experiment was considered to reflect reality: 39 of 40 participants were males (97%). A number of criteria had to be fulfilled in order for a potential participant to be signed up, and these generally related to health issues. All participants needed to possess an ENG1 certificate and not suffer from any well known sleep disorders, such as sleep apnoea.

Travel arrangements and reimbursement for most participants was arranged by a marine manning company – SeaMariner, based near Warsash. A pool of seafarers was ready to be involved in the experiment, mainly because of the presence of suitable student candidates on campus. Yet, the assistance of the manning agency was vital in ensuring that a sufficient number of participants could be found. Any volunteers and student candidates from WMA had to join the manning agency in order to take part in the experiment. This was a necessary requirement, in order that professionals could check the visas of the overseas participants and to arrange their travel and payment.

5 The Measurement of Sleepiness Levels

A variety of methods was used to gauge the sleepiness levels of the participants throughout the week. All the measures had been validated through previous research, and they ranged from diary keeping to the use of electrodes to record brain activity. The following subsections describe the main methods used in the data analysis:

5.1 Diaries

Each participant had to fill in a set of diaries and a number of questionnaires before, during and after the experiments. Diaries were kept to record the levels of sleepiness, as measured on the Karolinska Sleepiness Scale (KSS), and stress. The KSS scale ranges from 1=extremely alert to 9=extreme tiredness. This was recorded every hour on watch, and on the hour off watch, if the participant was still awake. At the end of the watch, participants were also asked to record their food intake on watch, how well they thought they had performed, and their perceptions of the workload.

A wake diary also allowed participants to record other activity while off watch, such snacks taken, and the type of activity taken during free time. Participants were allowed to use the Academy's gymnasium but only under controlled conditions up to one hour immediately after watch each day.

A sleep diary was completed on waking after each period of rest and focussed on the quality of sleep in the last off watch period. Data was sought on how quickly participants fell asleep, how often they woke, difficulties experienced in sleeping, and how refreshed they felt on awakening.

5.2 A psycho-vigilance test (PVT)

The psychomotor vigilance task (PVT) is a vigilance test which is sensitive to fatigue. The PVT was performed on portable devices, always before starting a simulator watch, and once

on completion of a watch. This means 28 test results were recorded for every participant by the end of the run. Once initialised, the PVT test presents a target to the participant on a small screen at random intervals, and the participant has to press a button to record when the target is seen. Each test lasted approximately five minutes, and the reaction time, the number of lapses, the mean reaction time, etc. were all recorded and stored on the device.

5.3 EEG Recordings

EEG recordings measure the electrical activity of the brain, through several electrodes that are attached on the head. The participants were fitted with these on two occasions during the week by specialists. This occurred on the second and sixth days, and the participants wore them for a complete 24 hour period, thus wearing them for two watches and for two rest periods. The data recorded for the off watch periods is particularly valuable, as it provides an objective picture of exactly when the participant was falling asleep and the quality of that sleep. The data also allows the analysis for micro-sleeps during periods of watch keeping and this aspect will form an important part of the final results and findings from the project. One other test was conducted at the end of each watch when participants were wearing the electrodes. This is the Karolinska Drowsiness Test, and requires participants to stare at a black spot on the wall for five minutes before closing their eyes for a further five minutes. During this period, the EEG is recording brain activity, and the length of time before a participant starts to fall asleep with eyes closed is an important objective measure of the real state of tiredness at that time.



Figure 2: Protection of electrodes using a hairnet in the Engine Control Room Simulator

6 Fatigue and Performance Results

The full results can be found at www.project-horizon.eu. However, the following general conclusions can be drawn:

- The data supports previous research findings and circadian theory. Watch keepers are most tired during the night watches and also show signs of tiredness in the afternoon;
- Sleepiness and neurobehavioral performance, as measured by the EEG electrodes, are particularly affected towards the end of the 0000-0600 watch. Sleepiness and fatigue are enhanced and brain performance reduced. In addition, there is a gradual increase of fatigue during the work periods as the week progresses.
- Occurrences of small periods of sleep have been shown through analysis of the EEG recordings, both on the bridge and in the engine room. About 20% of participants fell asleep at some point during the 6/6 watch regime
- From the evidence of the sleep diaries, The 6 hours on /6 hours off watch regime is more tiring than the 4on/8off;
- The onset of tiredness on the 6on/6off was apparent over a shorter timeframe than might have been predicted by previous research;
- “Disturbed” rest periods produce significantly higher levels of tiredness: the quality of sleep is more significant than the workload.
- The data appears to be robust enough to provide input to future marine-validated fatigue prediction models

This final point is an important one. It is hoped that HORIZON, in addition to providing guidance to individual seafarers and managers on ensuring good quality sleep, will be able to make a major contribution to the welfare of seafarers by contributing data to the production of fatigue prediction software. Such technology will help seafarers to plan their work schedules and disturbances to the normal watch keeping patterns in such a way as to mitigate the risk of fatigue.

The analysis of “naturalistic” performance is still ongoing but a number of problems and issues have been encountered, which may be of interest to future researchers. These include:

- 1 Some “events” were not as repeatable as others, for example, although some events involving repetitive procedural responses are easily initiated, other events such as collision avoidance situations are not so easily set up on every occasion;
- 2 Some performance criteria for measuring performance during these events are more valid and reliable than others.
- 3 Watch handovers were a significant source of data for checking alertness and the overall performance of watch keepers. As noted before, in the light of the *Shen Neng1* grounding, handovers represent a major opportunity for errors to occur. There

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appeared to be a significant deterioration in watch handover performance as the week progressed, and this will need to be verified.

- 4 There was significant variability in the competence displayed by watch keepers. This was due to the randomness of the candidate selection process. Although there were good performers, there were also some watch keepers who seemed barely competent.
- 5 Social interaction and levels of communication appeared to be related. When bridge and engine room watch keepers got on well in the mess room, this translated into effective communication on watch. When personality or other differences between participants were apparent, communication suffered.
- 6 Some procedural tasks (drills) seem more resilient to fatigue than novel situations requiring thought (cognitive skills). In addition, some watch keepers were apparently more resilient to fatigue, but we need to investigate what factors might influence this.

References

ATSB (2010) "*Independent investigation into the grounding of the Chinese registered bulk carrier **Shen Neng 1** on Douglas Shoal, Queensland. Marine Occurrence Investigation No. 274 MO-2010-003 03 April 2010*