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TNO report

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Safety consequences onboard shortsea ships due to a new way of working

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Summary

International marine legislation sets a high, but conservative standard to the ship's crew, but other compositions of the ship's crew may fulfill these high standards as well. We have investigated such an alternative assignment of manning on board modern Dutch coasters and show that the current level of safety is maintained.
One standard is the obligation to have a Chief Engineer on board ships with a propulsion power higher than 749 kW. The Chief Engineer has received mono disciplinary education for the engineering department and cannot execute navigational tasks. Since modern coasters are equipped with engines requiring only a minimal level of maintenance, a Chief Engineer may use his time more effectively. He may also be replaced by a beginning Maritime Officer (Marof) who has received a dual education in both navigational and engineering skills. A Marof may do maintenance and take over some shifts from the Master and the Chief Mate.
The advantage is a more flexible way of operating the ship. To compensate for the reduction of technical knowledge and skills onboard, the MAROF is backed up with 24 hours onshore technical support. This new crew concept is potentially relevant for 320 Dutch shortsea ships. The acceptance of this new assignment is important since it contributes to providing a solution to a serious shortage of Chief Engineers that has been forecasted.

TNO has piloted this new crew concept and quasi-experimentally compared it to the traditional manning on shortsea ships. The study involved 21 shortsea ships, all with a propulsion power between 749kW and 3000kW, running on Marine Gas Oil / Marine Diesel Oil, and sailing within Europe. We have carried out measurements on 311 voyages, in over 16,000 shifts and in almost 60,000 hours.
These measurements were provided by the Masters, Chief Mates and Chief Engineers c.q. Marofs. During their work, they answered on a PDA questions about the specific conditions (such as the situational circumstances), the navigational and engineering process (such as workload and tiredness, but also the amount of sleep, and off-shore support), and the safety outcome (such as critical incidents and subjective safety assessments). Additional data were collected by means of questionnaires and interviews.

We can conclude from the results that sailing with a Marof combined with shore support is at least as safe as sailing with a Chief Engineer. No indications have been found that Marof ships function technically less well than Traditional ships. The results further indicate that on Marof ships, the shifts went more satisfactory and the crews were less tired compared to traditional shortsea ships, which contributes to the avoidance of fatigue of the navigation officers.

Contents

1 Introduction

The study reported here investigated an alternative assignment of manning on board of coasters while maintaining the current level of safety. At this moment, the international marine legislation sets a high, although conservative, standard to the ship's crew and their qualifications. As a consequence of the modernization of the ships, the question can be raised whether another composition of the ship's crew can also fulfill these high standards.
One example of such a standard is the obligation to have a Chief Engineer on board ships with a propulsion power higher than 749 kW. The Chief Engineer has received mono disciplinary education in the engineering department. He cannot, for example, execute navigational tasks. Since modern ships are nowadays equipped with engines that require a minimum of maintenance and repair, the question is whether a Chief Engineer can use his time more effectively on this type of ships. One possibility is to replace the Chief Engineer by a beginning Maritime Officer (Marof) who has received a dual education in navigational as well as in engineering skills and, as a result, is able to perform tasks in both disciplines. For example, the Marof can take over tasks of the Master and the Chief Mate. The advantage is that this composition of the ship's crew allows a more flexible way of operating the ship. To compensate for the reduction of technical knowledge and skills onboard, the Marof is backed up with 24 hours onshore technical support. This new crew concept is potentially relevant for about 300 Dutch shortsea ships [see TWMI, 2009].
The acceptance of this new assignment is important since it contributes to a solution to a serious shortage of Chief Engineers that has been forecasted, world-wide. Currently, there is a shortage of Officers of 2%, which in a 'cold' scenario remains at that level, but most probably grows to 5%, and in a 'hot' scenario to even 11%. For Chief Engineers, the predictions are even worse [BIMCO/ISF, 2010].

We have piloted this new crew concept and quasi-experimentally[1] compared it to the traditional manning on shortsea ships. The work plan for this pilot is based on [Punte & Rasker, 2007].

There were strict requirements for the 21 participating ships (see 4.1.4), such as:
- The ship's gross tonnage is less than 3000 GT.
- The ship is operated in the shortsea shipping within the European waters.
- The ship's propulsion power is between 749kW and 3000kW.
- The ship is running on Marine Gas Oil / Marine Diesel Oil.

This report starts with discussing the literature on safe sailing. Next, it outlines the research method, followed by a description of the results. The report concludes with a discussion of the comparison.

[1] In contrast to randomized experiments, quasi-experiments by definition lack random assignment. In this study, assignment to conditions was by means of self-selection. Quasi-experimental control groups may differ from the treatment condition in many systematic (non-random) ways other than the presence of a treatment [Shadish, Cook, & Campbell, 2002].

2 Literature

Safe sailing has received much attention in the literature. For an overview, see Hetherington, Flin and Means, [2006]. We discuss three major topics that are relevant for developing the measurement instrument, described in the next chapter: Safety in complex systems, Situation awareness and Fatigue. In addition, national and international Legislation are discussed.

2.1 Safety in complex systems

The approach taken in this study is a comparison between two complex socio-technical systems, rather than an isolated comparison between two alternative members of a crew (i.e., the Chief Engineer and the MAROF). Safety research itself has evolved in the past 50 years from human error orientation, through systemic orientation as well as human machine cooperation in the 1980s, towards a strong interest in complex dynamic situations, field work instead of lab research, and limiting the unforeseen effects of badly designed systems, in the 1990s [Morel, Amalberti & Chauvin, 2008]. In the current decade, the concept of resilience has arisen. Resilience is also a system concept, in that it regards system safety as an aggregate of its various components, subsystems, software, organizations, human behaviours, and the way in which they interact. The novelty of the approach is that resilience is regarded as the ability of a complex system to adapt to the dynamic complexity of the real world, before failures and losses come about. See Hollnagel, Woods & Leveson [2006] for an introduction to this concept. One of the interesting aspects of this approach is that it helps addressing problems with the trade-offs between production and safety. This is certainly a feature for this study since the economic pressure of shipping is high.

2.2 Situation Awareness

One important aspect of safety in dynamic situations such as sailing is Situation Awareness (SA). Endsley [1995] subdivided this concept in three levels: perception, interpretation and anticipation. Chauvin, Clostermann and Hoc [2008] found that for novices, the perception of the elements in the environment (level 1 SA) is of secondary importance in safe sailing. More important are the interpretation of the Rules of the Sea (level 2 SA), and the anticipation of the other vessel's intention (level 3 SA). Novices use a more rule based decision making process compared to the skill based approach that experienced people have developed over the years. Marofs are less experienced, compared to Chief Mates and Masters. Since rule based decision-making requires more effort, Marofs are expected to be more vulnerable for tiredness.

2.3 Fatigue

Fatigue onboard has received a growing awareness in recent years [Patraiko, 2006]. For a complete, international account of the studies done in this area, see Smith [2007]. Although one of the earliest studies was done already two decades ago [Pollard, Sussman & Stearns, 1990], measures to deal with this serious problem haven’t prevented yet serious incidents, such as the grounding of the Klaipeda in the Baltic Sea, in October 2005, due to a master that had fallen asleep during duty. The International Maritime Organization provided a good account of all relevant factors already in 2001 [IMO, 2001]:

- Crew specific factors (sleep and rest, biological clock, psychological and emotional factors, health, stress, ingested chemicals, age, shift work and schedules, workload).
- Organizational factors (staffing policies, roles, paperwork, economics, company culture, resources, vessel upkeep, training and selection).
- Voyage and scheduling factors (frequency of port calls, time between ports, routing, weather, traffic density, nature of duties/workload while in port).
- Ship specific factors (level of autonomy and redundancy, equipment reliability, inspection and maintenance, vessel age, physical comfort, ship motion).
- Environmental factors (temperature, humidity, noise levels, ship motions).

Fatigue is related to sleep (duration, continuity and quality), the biological clock and circadian rhythm and stress (environmental, personal problems, long working hours, broken rest and on-board interpersonal relationships). Fatigue also endangers people's self-assessment of their own fatigue; a performance test would therefore assess fatigue better. Further, fatigue impairs attention and memory, increases errors and decreases efficacy. Chronic fatigue leads to selecting risky strategies that require less effort. Fatigue can affect all levels of SA and problem solving in novel situations.

2.4 Legislation

A number of national and international instruments are available that specify requirements concerning the number and specification of crew and (safety) means on board, the certifications of the crew, and the maintenance of (safety) means. These requirements are periodically re-examined during the life cycle of a ship [TWMI, 2002; TWMI, 2005; ILO, 1996; IMO, 2003; IMO, 1978; SOLAS, 1974; IMO, 2001].

3 Method

This chapter describes the development of a measurement instrument for capturing the right and sufficient data during a period of about eighteen months, to demonstrate that a new way of working on board is at least as safe as the existing situation. The approach is to pilot the new crew concept and quasi-experimentally compare it to the traditional manning on shortsea ships. The work plan for this pilot is based on [Punte & Rasker, 2007].

After discussing the literature, the chapter presents a framework covering various aspects related to safe sailing, which serves as the basis for the definition of the set of measurements. Next, the development of the instrument is described, followed by a presentation of the results of a pilot study to test it out.

3.1 Initial interviews

To become familiar with the domain, we interviewed three shipping companies about sailing with the new manning concept, and about the possibilities of onboard measurements. We identified four main voyage phases that differ in their character and require different measurements: under way, arrival / departure / pilot, moored, and anchored. Further, we illustrated differences between the manning concepts by means of the schedules, presented in Figure 3-1.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Conventional watch scheme																								
Master							1	2	3	4	5	6							7	8	9	10	11	12
Chief Mate	1	2	3	4	5	6							7	8	9	10	11	12						
Chief Engineer									1	2	3	4	5	6	7	8								
New watch scheme: Marof repacing the Chief Engineer																								
Master									1	2	3	4							5	6	7	8	9	10
Chief Mate					1	2	3	4					5	6	7	8	9	10						
Maritime Officer	1	2	3	4							5	6		7	8	9	10							

Navigation   Engineering   8 Cumulated working hours

Figure 3-1 Watch schedules for two different manning concepts. The columns represent the hours of the day; the rows the crew. Black cells show navigation hours, grey cells engineering hours. The numbers in the cells represent cumulated working hours within a day.

Three aspects are apparent from Figure 3-1. Firstly, in the conventional watch schedule, the Master and the Chief Mate work 12 hours a day, and the Chief Engineer only 8 hours (the shipping companies claim that the work is even much less than that, for these modern ship engines), whereas in the second watch schedule the number of working hours is evenly divided over the members of the crew.

Secondly, the nightly watches differ importantly between the conventional schedule and the new schedule. Not only is there an advantage for the Chief Mate, the effect of the circadian rhythm on the shift (especially causing problems between 5 and 6 AM) are expected to decrease, due to this shorter dark shift. Thirdly, for the future manning concept, there is a balanced division of both work hours and work domain, which may be favourable for shared awareness, crew adaptability, knowledge maintenance and job satisfaction.

3.2 Framework

The basis for our data capturing is the following conditions - process - outcome framework, developed especially for this study. Figure 3-2 shows this framework. The framework illustrates that safety depends on situational circumstances, personal competences, characteristics of the ship, and the shore organisation (both the shipping company and the shore support organisation). Through the main processes of navigation and engineering, and secondary processes of team support and shore support, the product of safe, economic, and environment friendly sailing is accomplished.

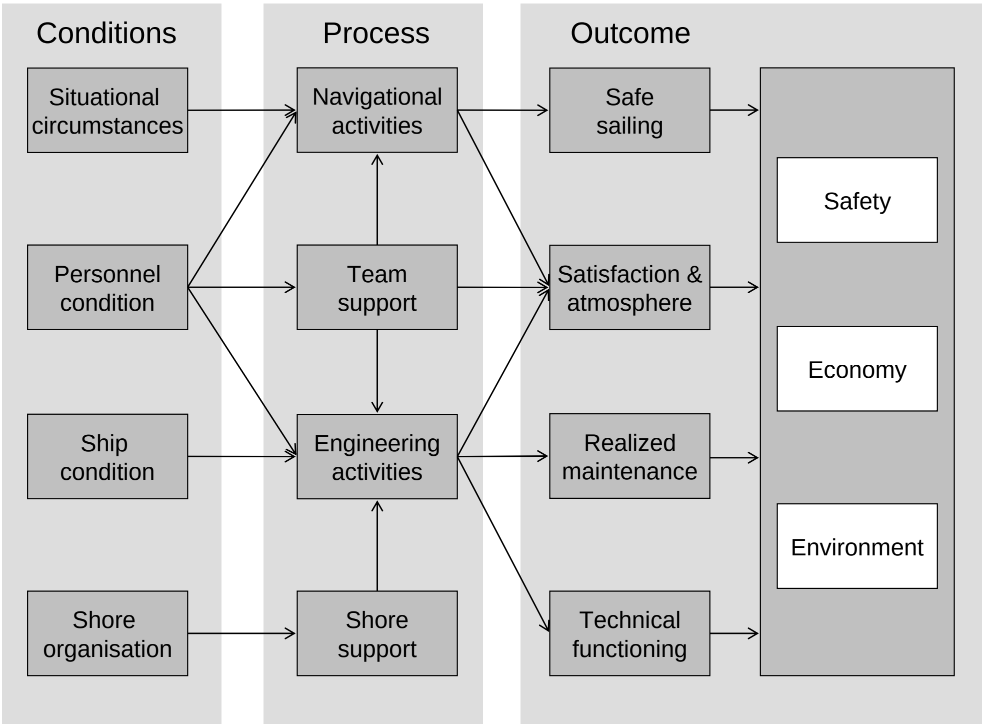


Figure 3-2 Conditions – process – outcome framework for safety related issues.

The elements in the framework were all measured in different ways. Below, we will outline by what means the elements were measured.

3.2.1 Conditions

- Situational circumstances: every hour, the voyage phase was measured; every shift, traffic density and meteorological data (visibility, sea state and state of vessel) were collected; every eighth hour, ship’s GPS data, speed and course were recorded.
- Personnel condition: each sailing term, personnel condition in terms of capabilities (such as knowledge, experience, communicability, assertiveness, etc.), was measured by means of questionnaires and interviews.
- Ship condition: state of maintenance (weekly measured by standard ship reports); ship characteristics, such as level of automation and support (measured once)
- Shore organization: measured on shore, by means of interviews.

3.2.2 Process

- Navigation activities: measured on an hourly basis in terms of who and when one navigates and how busy and how tired one is.
- Team support: relating the activities among the navigators.
- Engineering activities: measured each shift, in terms of how busy and tired one is, and how well one could keep up with the planned maintenance.
  Measured between shifts, in terms of the number of alarms that were handled, and the amount of time it took to deal with the alarms.
- Shore Support: measured aboard: collected after every shift and after each voyage, in terms of whether it was needed and how satisfactory it was.

3.2.3 Outcome

- Safe sailing: subjective assessments of how well the shift went and the occurrence, kind of, and handling of critical incidents, were measured every shift by asking personnel to indicate their assessments on a PDA; subjective assessments of how well and how safe the voyage went, and the occurrence and kind of calamities, were measured every voyage.
- Realized maintenance: measured every shift in terms of deviations towards a maintenance plan.
- Technical functioning: measured at shift level in terms of occurrences of malfunctioning.
- Safety: measured in terms of reported accidents.
- Optimal trade: measured in terms of timely arrival against minimal costs.
- Environment: measured in terms of pollution occurrence, as reported by the Master on a PDA, after every voyage.

3.3 Organisation of measurements

To understand and assess safe sailing for both manning concepts, all aspects in the framework were measured in this study, where the crew plays a central role.
During each sailing term, the Master, the Chief Mate, and, depending on the experimental condition, the MAROF or Chief Engineer, were asked to answer questions about all these aspects. These were presented on a Personal Digital Assistant (PDA), at certain points in time. Each of these members of the crew was asked a limited number of questions at the start (taking about 10 seconds) and at the end of each shift (taking about 30 seconds). For some members of the crew (the navigators), a few questions were asked each hour during their shift (taking about 6 seconds). After each voyage, the Master was asked specific questions about the whole voyage (taking about 30 seconds).

Further, after each sailing terms, all members of the crew were asked questions about that specific term. These questions needed to be filled out via a web questionnaire.
Also, at the start and the end of the study, additional questions were asked to all members of the crew, by means of web questionnaires. Finally, on special occasions such as after incidents, telephone interviews were held. The study was planned for 12 months and involved 25 ships of three shipping companies.
All Masters, Chief Mates, Chief Engineers and Marofs were planned to participate.
In addition, the ratings were asked to fill out electronic questionnaires, especially about the atmosphere and workload on board. Figure 3-3 presents these measurements over time.

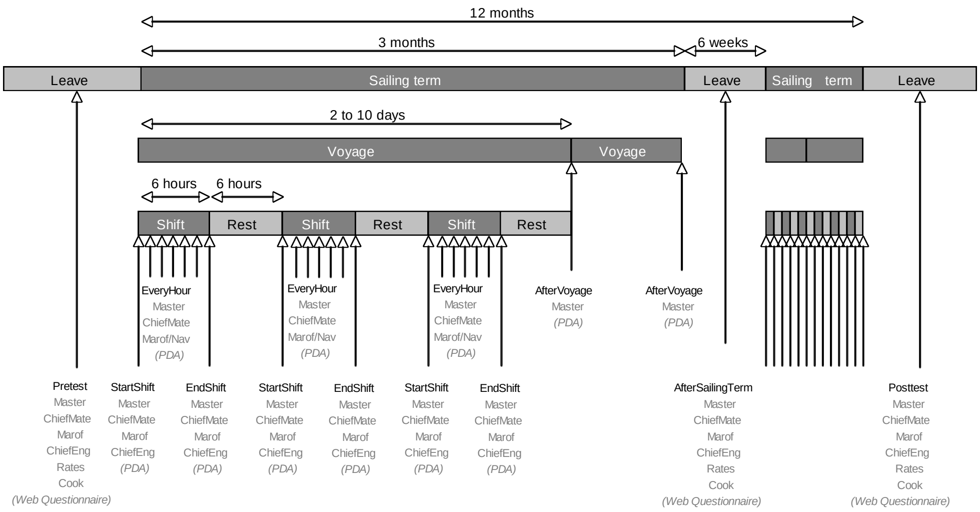


Figure 3-3 Overview of the planned measurements, taken at the start and end of the 12 month study, at the end of every sailing term, after each voyage within a sailing term, before and after each shift, and, during each shift, at every hour.

3.4 Instruments

PDA software was specially developed for this study. Asking personnel to collect data for a full year, during every shift, and for some members of the crew every hour of a shift, required special effort in designing the instrument to be as user friendly as possible. The touch screen was designed for finger operation.
Screen colours were used to provide feedback on mode (rest or shift) and role (navigation and engineering). Further, gentle alarms warned at proper times to fill out questions, or to remind filling out a series, once started; each screen contained seven questions at the most, and every answer provided can be undone. Figure 3-4 shows a flow of screen shots.
Apart from a user-friendly interface, robustness is key. Robustness was partially solved by choosing a rugged, mil specs PDA (N550, with Fujitsu Siemens backbone) as platform. Each Officer was provided with a personal PDA.
Different case colours were used, to prevent that PDAs were coincidentally mixed up. Further, in the software, power consumption was brought back to a minimum, to only require charging about once a week. Also, the users were not allowed to use other software than ours, to prevent changes of settings that could potentially jeopardize the function of our instrument.

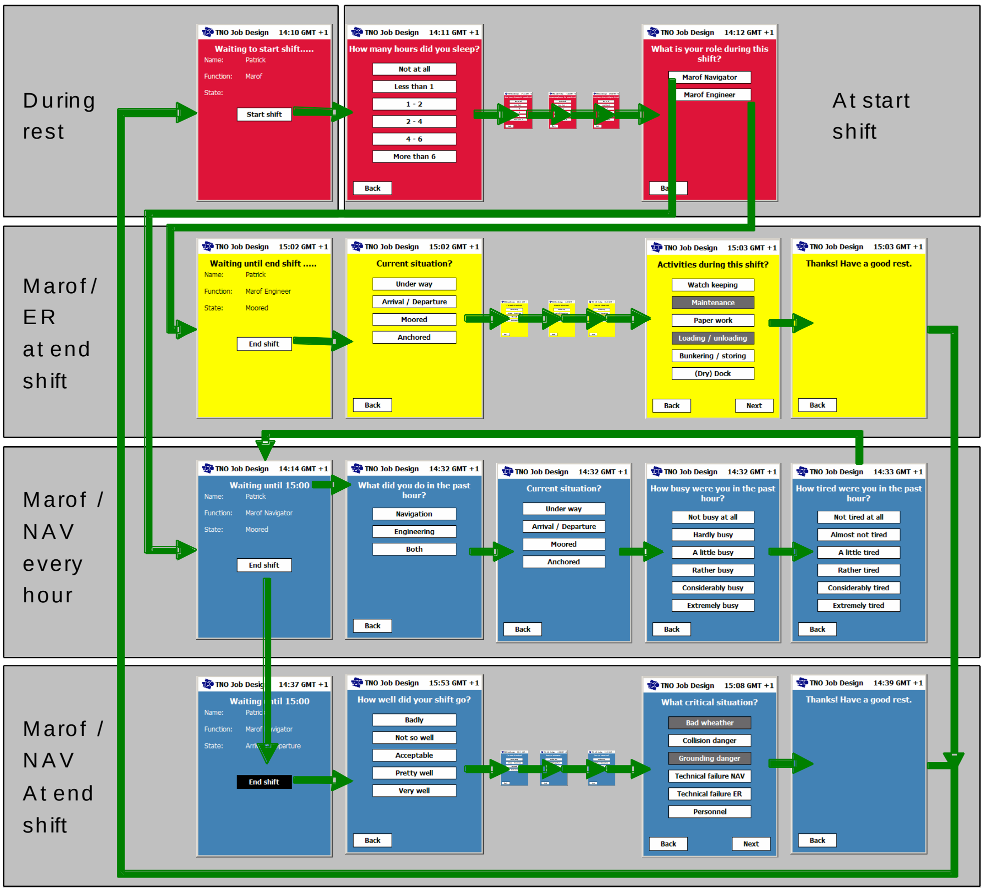


Figure 3-4 Flow of screenshots for the MAROF. During rest, a waiting screen is shown. After rest, a Start Shift button is pressed, starting a series of questions about the rest period. The MAROF is asked what shift to do: navigation or engineering. Depending on the answer, the PDA is waiting for the end of the shift (during engineering shift), or waiting to alarm the MAROF at clock stroke the hour, to ask questions about mental workload, tiredness and voyage phase (during navigation shift). After a shift, questions about the shift are presented.

In addition to a robust setup, a couple of data backup mechanisms were in place. First, a SD card stored the data permanently. Second, at least once a week, the data from the SD card was transferred to and backed up on a laptop or PC on board, only by placing the PDA in a cradle. Third, each week, the data was sent to us by satellite e-mail, and checked. In case strange things were detected, such as incompleteness and unreliability, the Master, responsible for the measurements on board, was notified. Technical problems were solved, either by using our manual, or by contacting us. Even a spare PDA was made available. This still did not prevent problems from occurring with our measurement instrument, since, as we knew from earlier studies, for curious users, hacking such a platform is very rewarding. Even then, the PDA could be reset easily, reinstalling the correct settings and restarting our measurement software.

3.4.1 *Two Pilot Trials*

The measurement instruments were tested by us during two voyages of multiple days, at two different ships. Below, we will report some findings of these pilot trials.

- At first, both crews were initially reluctant to use the PDAs for a whole year, but after a short while, they had no problems with it, showed great willingness to cooperate, and even suggested additional questions. Many valuable comments were given on the PDAs and our manuals.

- Our initial plan to do hourly measurements both in navigation and engineering was not feasible. In the engine room, alarms can't be heard, so we let the engineers fill out hourly questions about workload and tiredness directly after the shift. Hourly measurements were still feasible for the navigation department.
- At night, all lights are off on the bridge, except for the equipment. Our PDAs happened to be the greatest light source, so we had to develop day / night screens.
- Theoretical watch schedules, such as presented in Figure 3-1, turned out in practice to be much more fluent, especially in ports.
- We were 'fortunate' to be able to test out the instruments under extreme circumstances. During the first voyage, we sailed in a violent storm, and even for a short period a hurricane (12Bf). The PDAs literally flew through the ship's bridge. The kind crew excused themselves not filling them out anymore during that phase. Due to such circumstances we decided to buy rugged PDAs for the study, 96 in total. During the second voyage, it became clear that the manufacturer of this PDA had designed the waterproof case in such a way that the alarm can hardly be heard on a noisy navigation bridge. Measures were taken to deal with this, with the result that the alarm could always be heard (except in the engine room).
- Our experience with the storm provided us indications that a ship with its crew is a real complex socio-technical system. We will provide some examples.
  The decision to sail, while the storm was forecasted, was done under economic pressure, to save EUR 2000 harbour costs. Departure had to be done under time pressure, since the pilots were about to end their duty, resulting in a miscalculation of the distance and duration to the planned shelter. A minor technical malfunctioning (the connection between the GPS and the autopilot was sometimes lost, requiring some time for resetting, which would not be a problem under normal circumstances) in combination with extreme workload and tiredness (the weather demanded concentrated manoeuvring for many hours, and the crew weren't recovered yet from a previous storm), caused the ship to seriously role over 45^{o} once during the hurricane, resulting in serious damage onboard and minor injury.

4 Results

4.1 The conditions

In this section, an overview is provided of the participating crews, their voyages, their Officers and their shifts, and the ship conditions.

4.1.1 The types of crews

The shortsea ship crews that participated in this study are divided in two categories:

1. Traditional crews (henceforth referred to as “Traditional Shipping” or TS): crews that include a Chief Engineer.
2. Marof crews (henceforth referred to as “Marof Shipping”or MS): crews that have permission to replace the Chief Engineer with a Marof combined with 24/7 shore support.

In total, 21 ships from three Dutch shipping companies took part. Table 4.1 shows how the types of ships are divided over the shipping companies and how many voyages were made during this study. The voyages took place from April 2009 until September 2010. Appendix B lists the participating ships.

Table 4-1 Numbers of participating ships, over ship type (rows), shipping companies (columns) and the total number of ships and voyages. * The number of voyages is based on questionnaires filled out after each voyage. The actual number is higher.

Ship Type	**Shipping companies**			**Total Ships**	**Total Voyages***
	Amasus	**Flinter**	**Wagenborg**		
Traditional (TS)	3	3	3	**9**	**177**
Marof (MS)	1	2	7	**10**	**134**
Total	***4***	***5***	***10***	***19***	***311***

The size of the crews varied. In about 55% of the voyages, the ship sailed with 6 crew members; in 20 – 30% with 5, and in 20 – 30% more than 6. No statistically significant difference in crew size was found between the types of ships.

For each voyage, the following phases are distinguished:

- Under way.
- Arrival/departure/pilot.
- Moored.
- Anchored.

To give impression of the occurrence of these phases, as reported by the crews, at an hourly basis of their shifts, the ships were, on average, for 75% of their time underway, 13% of their time they were moored, for 7% of their time they were anchored, and for 5% of their time arriving or departing (including piloting).

4.1.2 The participants

In total 172 Officers participated in this study. Table 4-2 presents the distribution of roles and types of ships.

Table 4-2 Number of participants, their roles, and distribution across the types of ships.

	Master	Chief Mate	Chief Engineer	Marof	*Total*
Traditional (TS)	28	36	20		*84*
Marof (MS)	23	28		37	*88*
Total	*51*	*64*	*20*	*37*	*172*

The Masters and the Chief Mates were mainly Dutch. The Chief Engineers frequently had a foreign nationality; their age is usually over 40 years of age. A number of the participating Marofs just left school, others had more experience, but they were maximally certified for watch keeping Engineer. Their age varied from 22 to 30 years. All Marofs in this study had the Dutch nationality.

During the study, we have contacted the crew of 13 ships by telephone, and, depending on their availability, interviewed Masters 13 times, Chief Mates 3 times, Chief Engineers 2 times, and Marofs 10 times.

Also, we repeatedly asked the crews to fill out our web questionnaires. Only 18% of the crew filled out the pre-questionnaire, and 26% the concluding questionnaire. Therefore, the results from these questionnaires cannot be considered as representative.

4.1.3 The shifts

In the 311 voyages we followed, in total 16227 shifts and 57692 hours were measured. Table 4-3 shows how these shifts and hours are divided over the crews.

Table 4-3 Number of shifts and hours measured for the various crew members.

	Master	Chief Mate	Chief Engineer	Marof as Engineer	Marof as Mate	*Total*
Shifts	5940	4784	1996	869	2638	*16227*
TS	3776	3510	1996	-	-	*9282*
MS	2164	1274	-	869	2638	*6946*
Hours	28119	19662	-	-	9911	*57692*
TS	18896	15628	-	-	-	*34524*
MS	9223	4034	-	-	9911	*23168*

4.1.4 Ship conditions

All participating shortsea ships fulfilled the following requirements:

- The ship was no passenger of tanker ship.
- The ship's gross tonnage was less than 3000 GT.
- The ship was operated in the shortsea shipping within the European waters (including 200 nm Exclusive Economic Zone).
- The ship's propulsion power was between 749kW and 3000kW.
- The auxiliary machinery was not complex.
- The engine room was of the periodically unattended machinery space arrangement in accordance with the rules of a classification society.
- The ship was running on MGO/MDO, as described by ISO 8217:2005.
- The propulsion as well as the steering power were to be maintained or immediately restored in case of a blackout.

4.2 The process

In this section, all activities measured are described, in terms of navigation, engineering, team support and shore support.

4.2.1 Navigational activities

At the start of each shift, and every hour during each shift, the navigators had to answer three questions on their PDA, about the current voyage phase, their work load and how tired they were.

The Master

The results for the Masters are based on measurements on 19 ships, in total 5940 shifts and 28119 hours. During each shift, at clock stroke the hour, the “current voyage phase” was asked. Figure 4-1 shows the percentage of voyage phases for the different types of ships. The TS Masters were in 74% of the time underway, 13% moored, 7% anchored, and 6% arriving or departing (including piloting). The MS Masters were 68% underway, 17% moored, 9% arriving or departing, and 6% anchored. A statistical significant difference is found in hourly reported voyage phases ($\chi^2(3)=200{,}49$, $p < .001$). TS masters reported to be more often underway, whereas MS masters reported more often Arriving/Departing/Piloting and Moored.

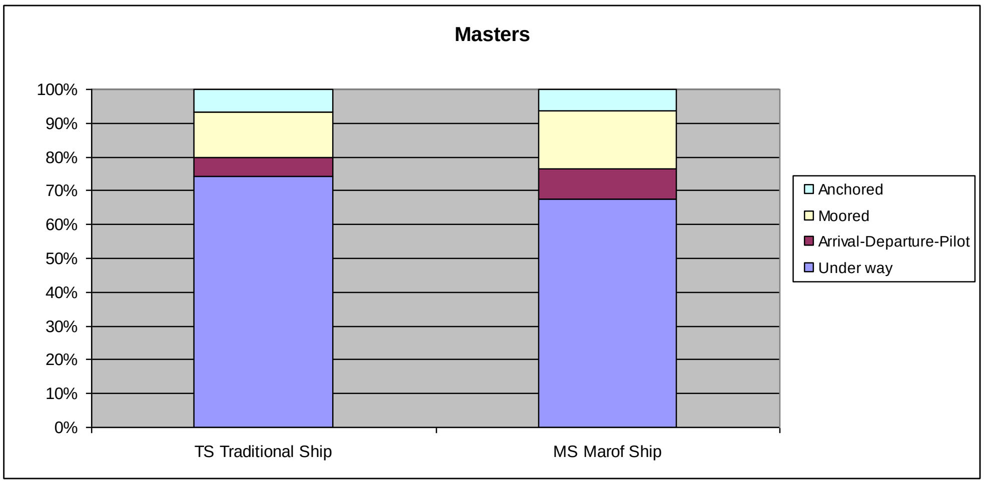


Figure 4-1 Percentage of voyage phases for the different types of ships.

Figure 4-2 shows that on average, the Masters are “little busy”. During arrival/ departure/piloting and when moored, the Masters are more busy, and when under way or anchored, less busy than on average (significant main effect of voyage phase: $F(3,45) = 37{,}92$; $p < .001$). Further, the data do not show a significant difference between the TS and the MS ships (mixed effects ANOVA on aggregated data on ship type, ship-level: $F(1,15)=3{,}34$, n.s.).

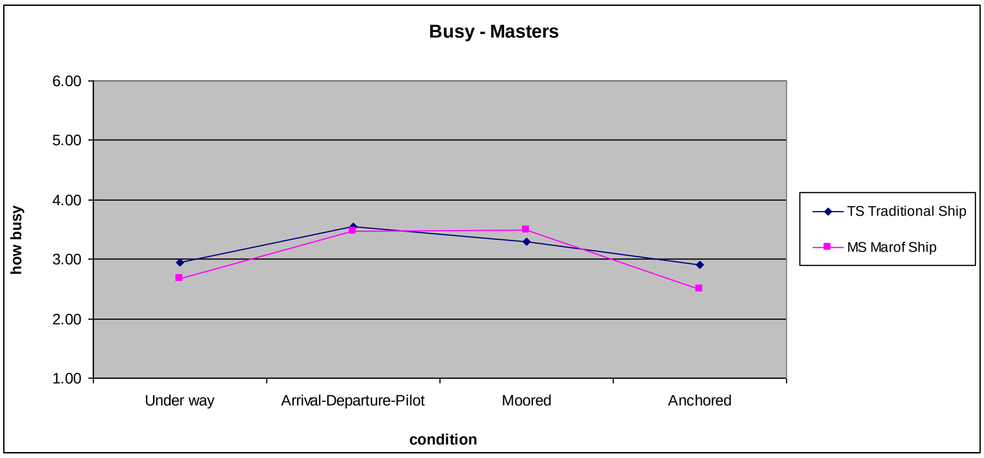


Figure 4-2 Workload of the Masters on both types of ships, as measured at every hour of the watch, and shown for the four voyage phases. Score 1 = not busy at all ; 2 = hardly busy; 3 = a little busy; 4 = rather busy; 5 = considerably busy; 6 = extremely busy.

Figure 4-3 shows that TS Masters report higher levels of tiredness than MS Masters. On average, the Masters report to be “hardly tired”, in all voyage phases, but Arriving/departing/piloting is the most tiring phase (Mixed effect ANOVA on aggregated data shows statistically significant differences between ship types: $F(1,15)= 10,12$; $p < .01$, and between voyage phases: $F(3,35)=3,47$; $p < .05$).

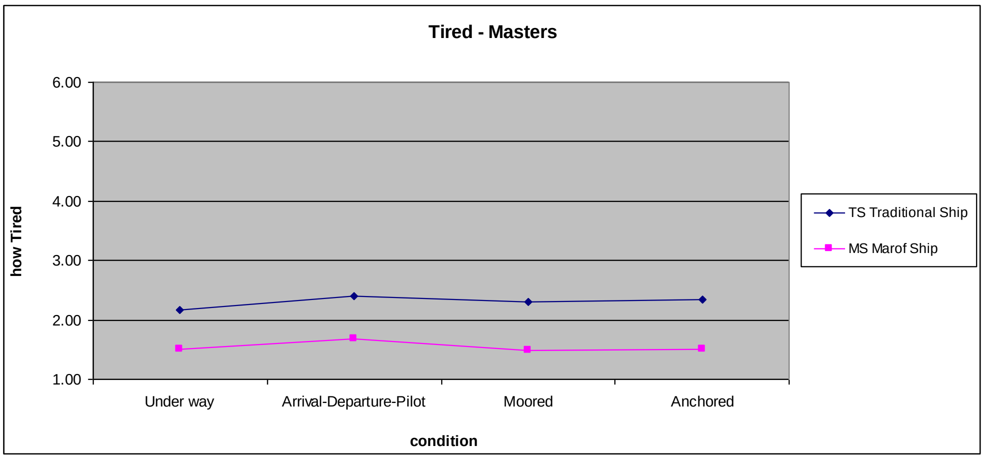


Figure 4-3 Tiredness of the Masters on both types of ships, as measured at every hour of the watch, and shown for the four voyage phases. Score 1 = not tired at all ; 2 = hardly tired; 3 = a little tired; 4 = rather tired; 5 = considerably tired; 6 = extremely tired.

Figure 4-4 illustrates the % active watch hours of the Masters, divided over the 24 hours of a day, at both types of ships, and shown for the four voyage phases.
It shows that when underway and when anchored, the TS Masters are, compared to the MS Masters, active with navigation for a longer period of the day. The MS Masters seem to take more rest when the circumstances allow it.
During arrival/departure/piloting, the Masters don’t follow a strict shift-rest schedule anymore: they frequently take the conn in this more demanding voyage phase.
When moored, the Masters make longer days, but sleep long during the night.

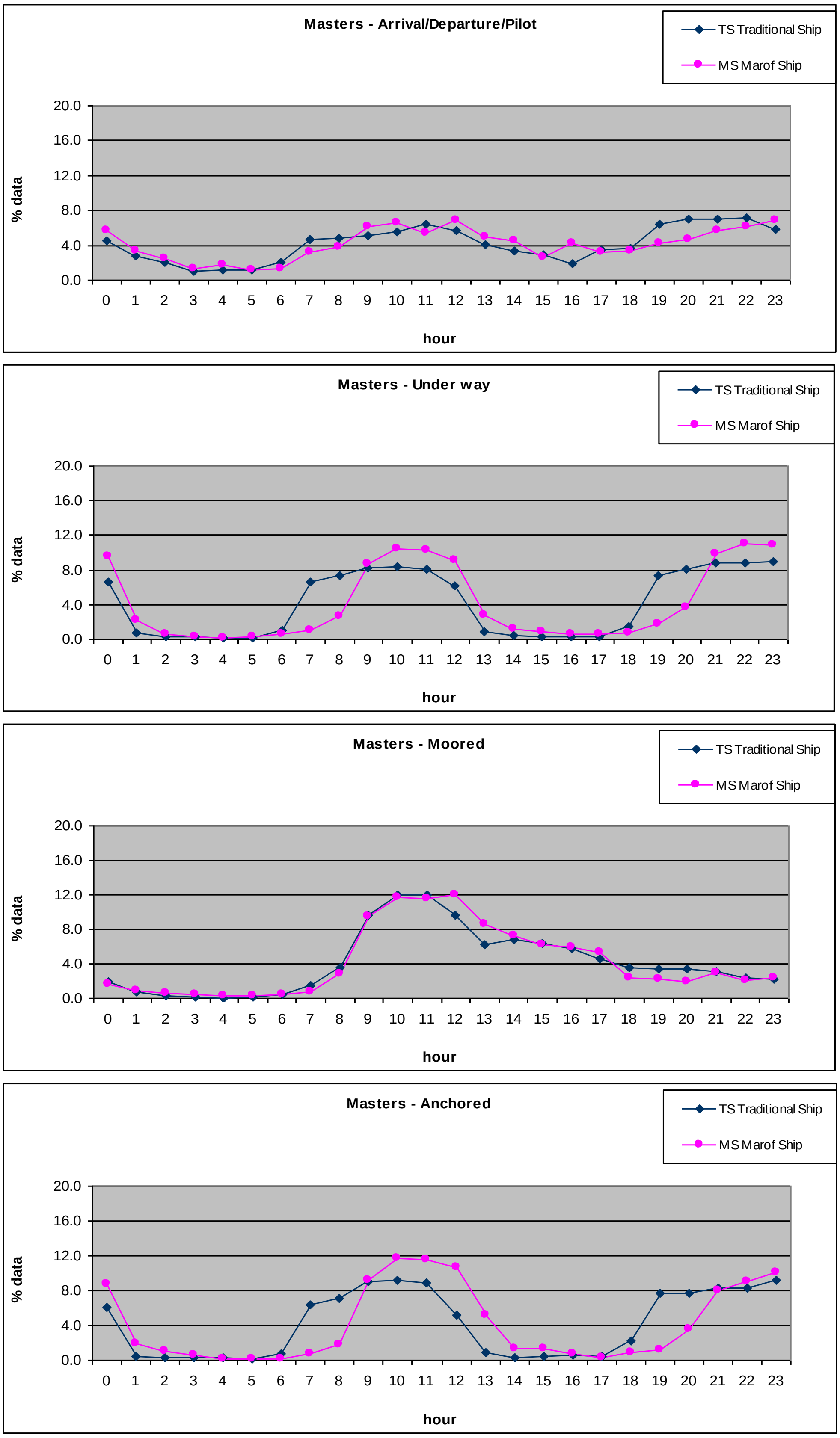


Figure 4-4 % watch hours of the Masters, divided over the 24 hours of a day, at both types of ships, and shown for the four voyage phases.

Figure 4-5 shows the answers to the question “How many hours did you sleep?”, which was asked at the start of each shift. The graph shows that for both types of ships, in approximately 40% of the time the Masters sleep 4 hours or less.
The TS Masters sleep more than 6 hours in only 10% of the shifts, while for the MS Masters, this is the case in 40% of the shifts (a statistical significant difference: $\chi^2(5)=844{,}21$, $p < .001$). This difference may contribute to limit fatigue. Note that the figure shows the hours of sleep both during the day and at night.

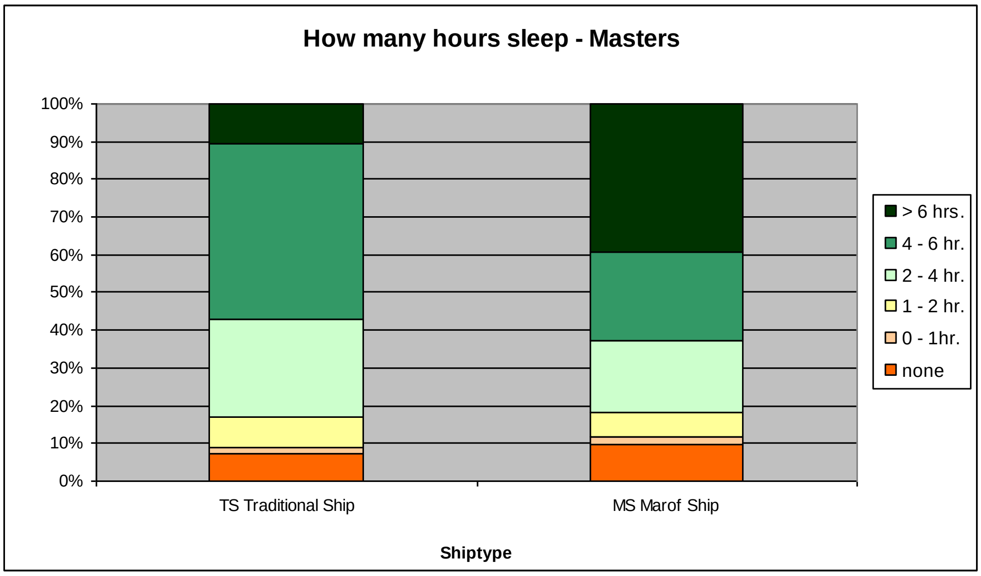
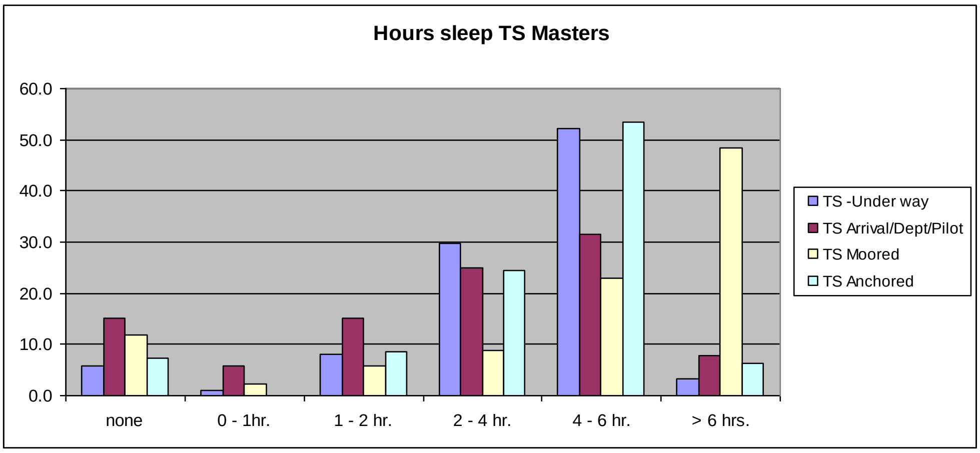


Figure 4-5 Amount of sleep of the Masters, during the day and at night, at both types of ships.

Figure 4-6 shows that the TS Masters sleep only six hours or more when moored. The MS Masters also sleep six hours or more when anchored, under way and during (or probably just before) arrival/departure.



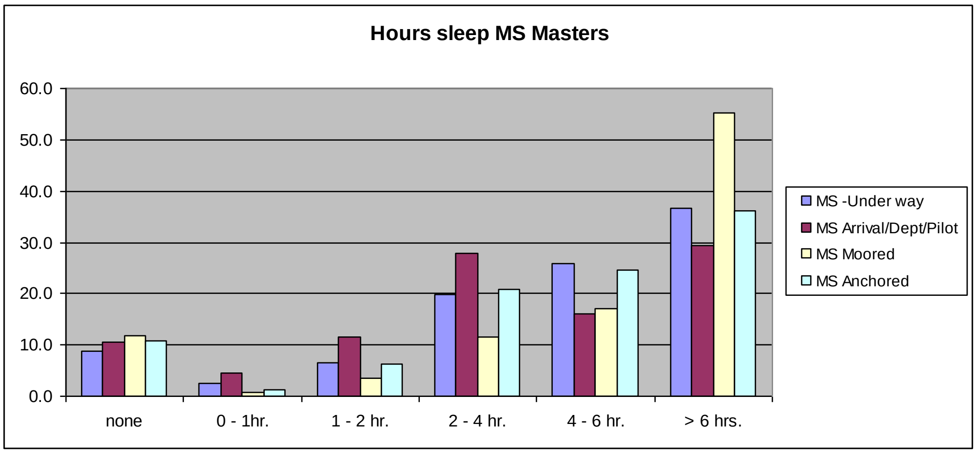


Figure 4-6 Amount of sleep of the Masters, for the different ship types and for the four different voyage phases.

At the start of a shift, the Master is asked how many calls he has had during his rest period. Figure 4-7 shows the number of times the Master is called for the different types of ships. The TS Masters are called in 7% of their shifts, the MS Masters 13.4% (overall). Most of the time, they are called only once.

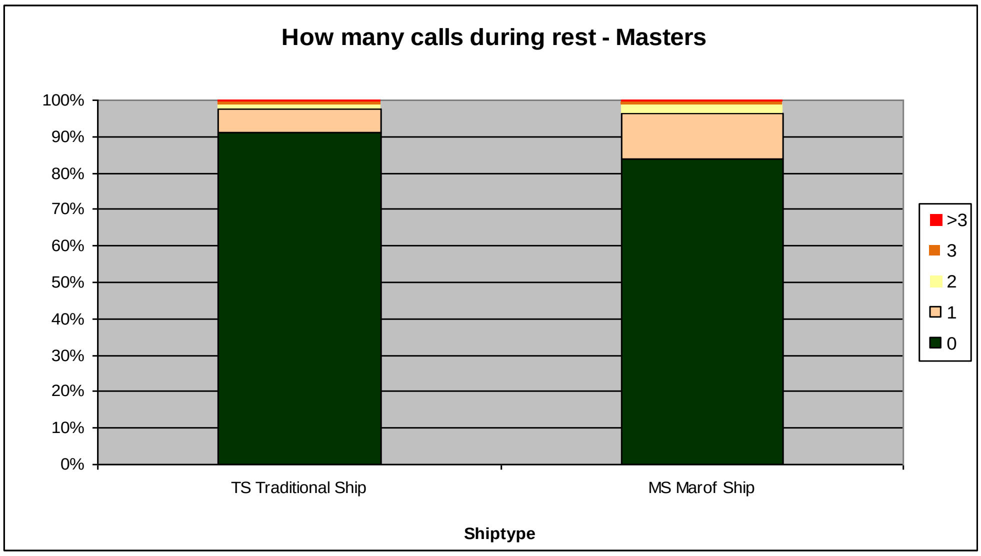


Figure 4-7 Number of times the Masters are called during rest, for the different types of ships.

At the start of a shift, the Master is also asked whether he had to do additional work during rest. Figure 4-8 shows that the MS Master has more often other additional work to do during rest compared to the TS Master (30% versus 20%). For both Masters, additional work consists mainly of paperwork (10% for both Masters). Compared to the TS Master, the MS Master has somewhat more nautical work (9% versus 4.5%), somewhat more maintenance work (5% versus 2.5%), and somewhat more management (5% vs 2,3%) These differences were statistically significant ($\chi^2(5)=138{,}21$, $p < .001$). As is shown in Figure 4-9, the total amount of time spent during the rest periods to additional work is substantial (over one hour) in 7% of the shifts of the TS Masters and 12% of the shifts of the MS Masters.

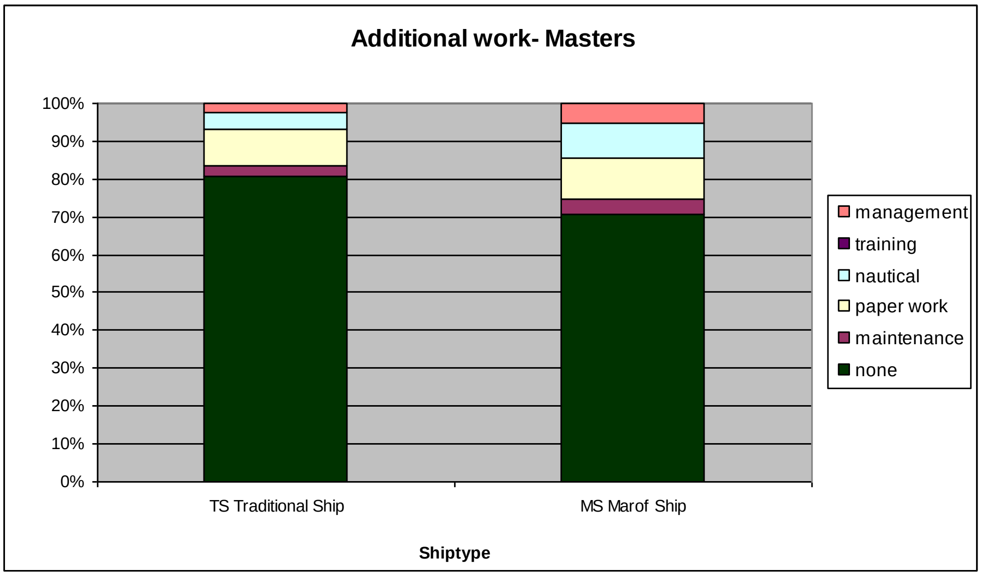


Figure 4-8 Type of additional work the Masters had to do during rest, for the different types of ships.

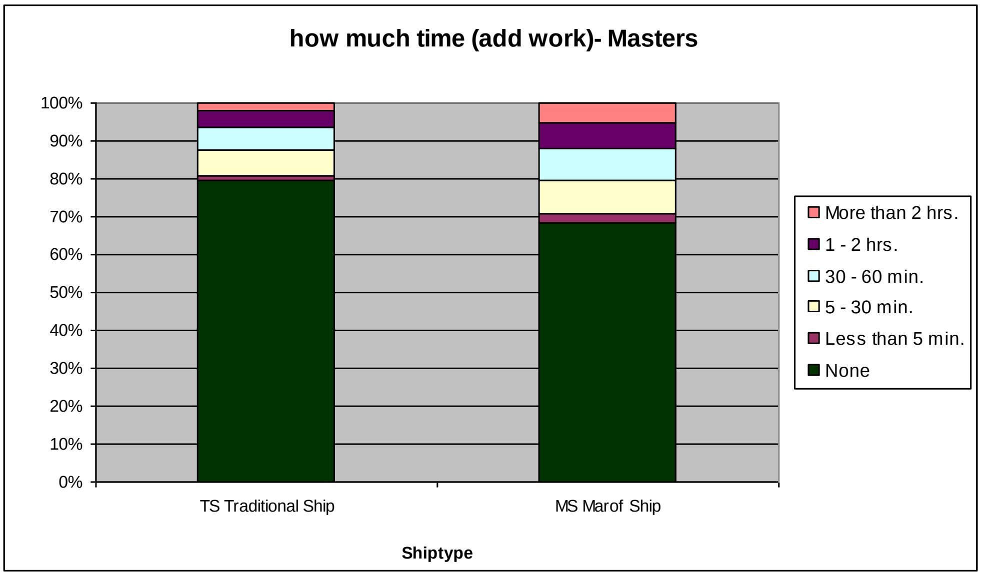


Figure 4-9 Amount of time the Chief Masters spent on the calls and additional work during rest, for both types of ships.

The Chief Mate

The results for the Chief Mate are based on measurements during 4784 shifts (3510 shifts at Traditional ships and 1274 shifts on Marof ships).

Figure 4-10 shows that the Chief Mates on both types of ships report equal voyage behaviour. Both types of ships are in 75% underway, in 14% moored, in 7% anchored and in 3% arriving/departing/piloting.

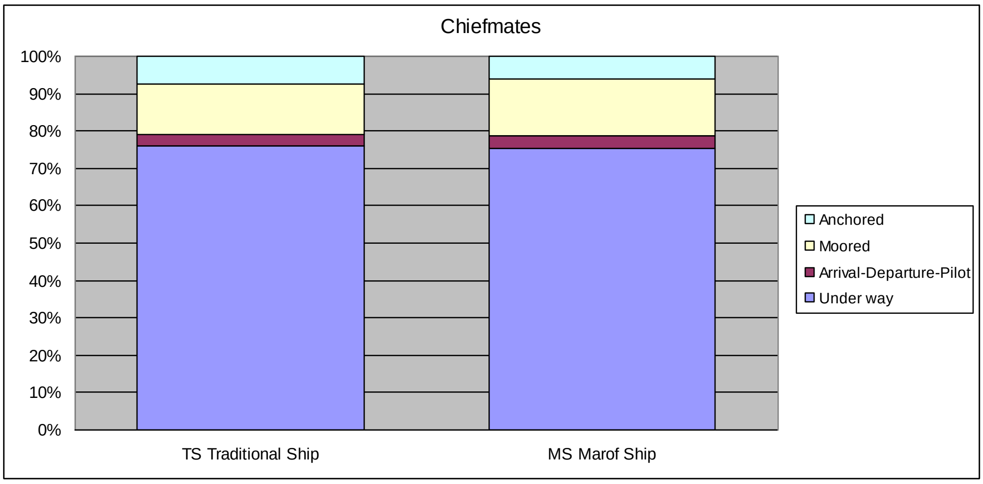


Figure 4-10 % Chief Mate shifts over voyage phases, for Traditional and Marof ships.

Figure 4-11 shows that, on average, the Chief Mates are “little busy”. Chief Mates were significantly more busy at Arrival/Departure-Pilot and Moored than at the other two voyage phases ($F(3,42) = 15,15$; $p < .001$)). Further, the data do not show significant differences between the TS and the MS ships. Figure 4-12 shows that, on average, the Chief Mates report to be “hardly tired”, in all voyage phases. There is a no statistical significant difference found between the tiredness of the Chief Mates, nor for the voyage phases, nor between both types of ships.

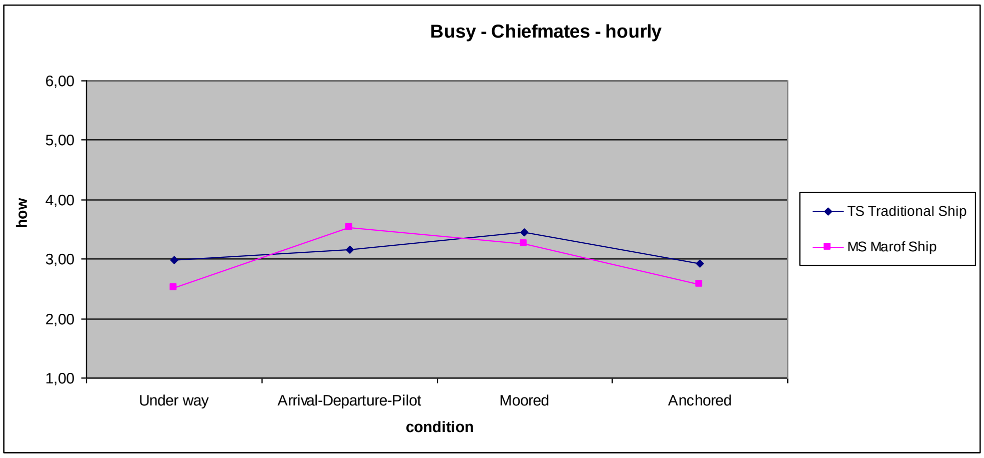


Figure 4-11 Workload of the Chief Mate on the Traditional and Marof ships, as measured at every hour of the watch, and shown for the four voyage phases. Score 1 = not busy at all ; 2 = hardly busy; 3 = a little busy; 4 = rather busy; 5 = considerably busy; 6 = extremely busy.

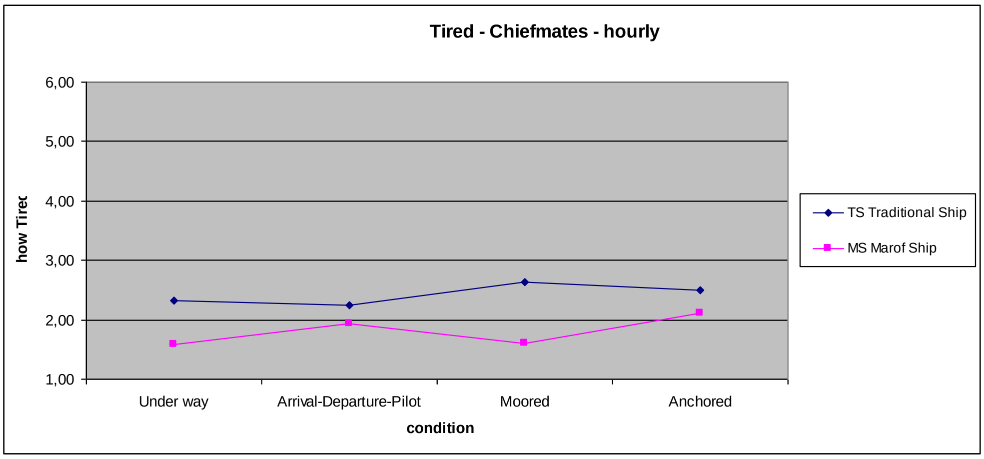


Figure 4-12 Tiredness levels of the Chief Mates on the Traditional and Marof ships, as measured at every hour of the watch, and shown for the four voyage phases. Score 1 = not tired at all ; 2 = hardly tired; 3 = a little tired; 4 = rather tired; 5 = considerably tired; 6 = extremely tired.

Figure 4-13 illustrates the % watch hours of the Chief Mates of the Traditional and Marof ship, divided over the 24 hours of a day, and shown for the four voyage phases. For the TS Chief Mates, when underway, a clear six hours shift scheme is shown. The MS Chief Mates, when underway, seem to have a four hours shift – eight hour rest scheme, where some start, roughly, at 2400 and 1200, and others at 0400 and 1600.

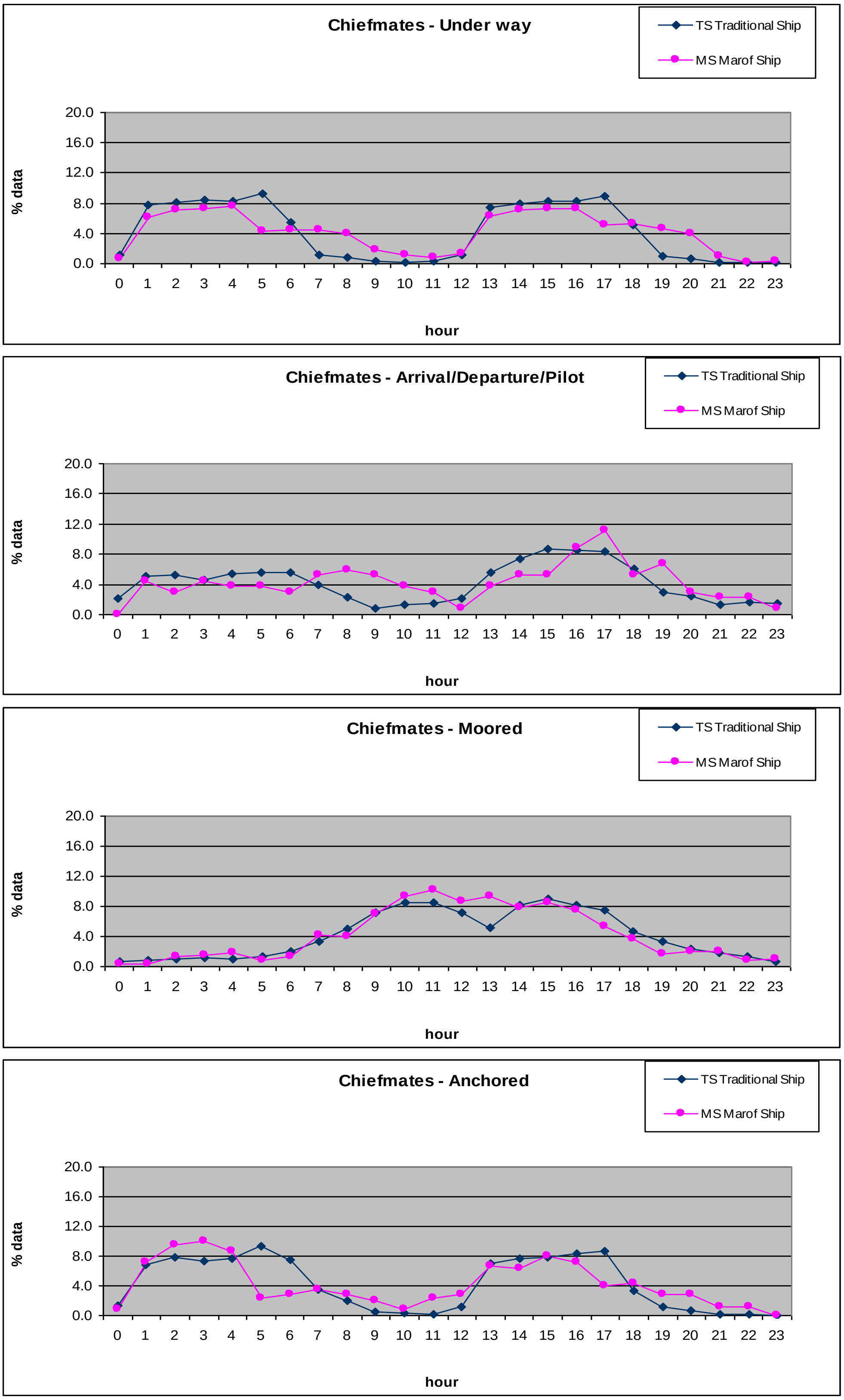


Figure 4-13 % watch hours of the Chief Mates, divided over the 24 hours of a day, at the Traditional and Marof ships, and shown for the four voyage phases.

Figure 4-14 shows that the Chief Mates at the Marof ships sleep statistical significantly more often over six hours, compared to the Chief Mates at the Traditional ships ($\chi^2(5)=236{,}02$, $p < .001$). Figure 4-15 shows that MS Chief Mates sleep especially more often over six hours when underway, moored, or anchored.

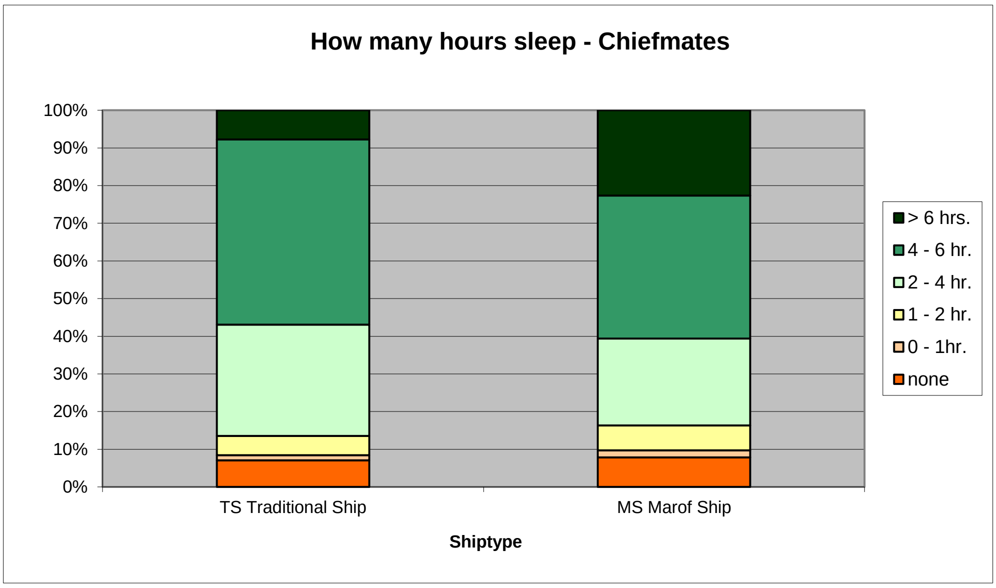


Figure 4-14 Amount of sleep of the Chief Mates, during the day and at night, at the Traditional and the Marof ships.

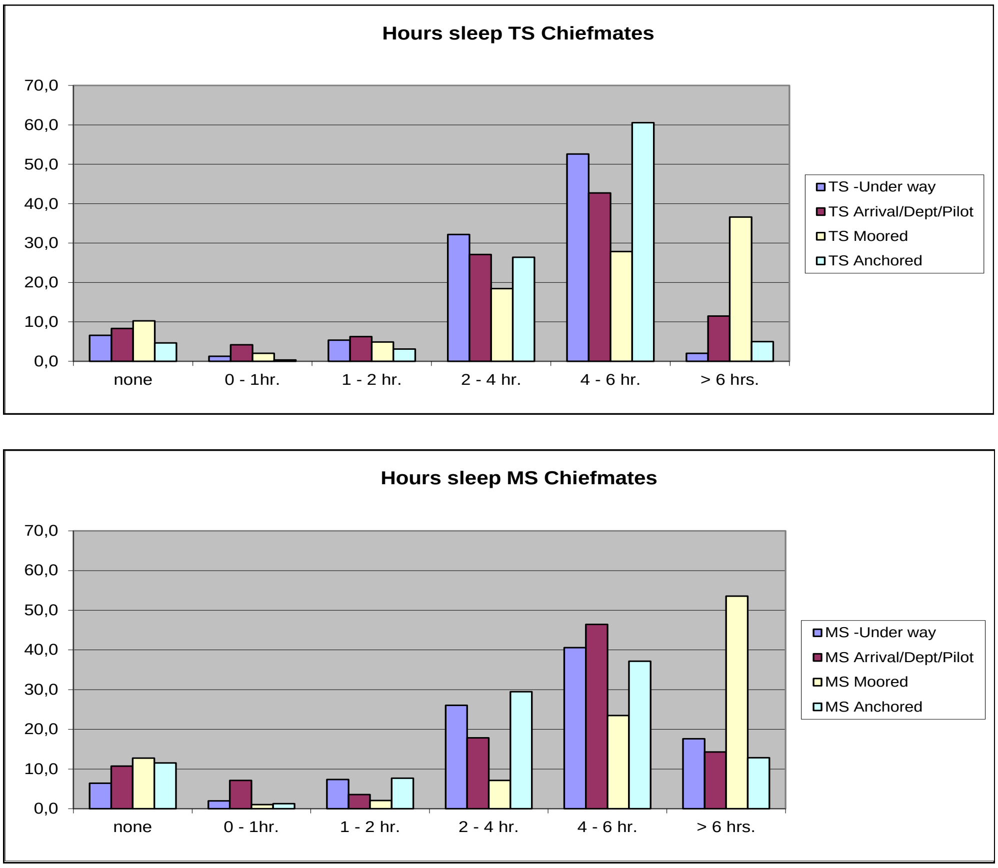


Figure 4-15 Amount of sleep of the Chief Mates, for both types of ships and for the four different voyage phases.

Figure 4-16 shows the number of times the Chief Mate is called for the different types of ships. The TS Chief Mate is called in 8% of his shifts, the MS Chief Mate 5%. Most of the time, he is called only once.

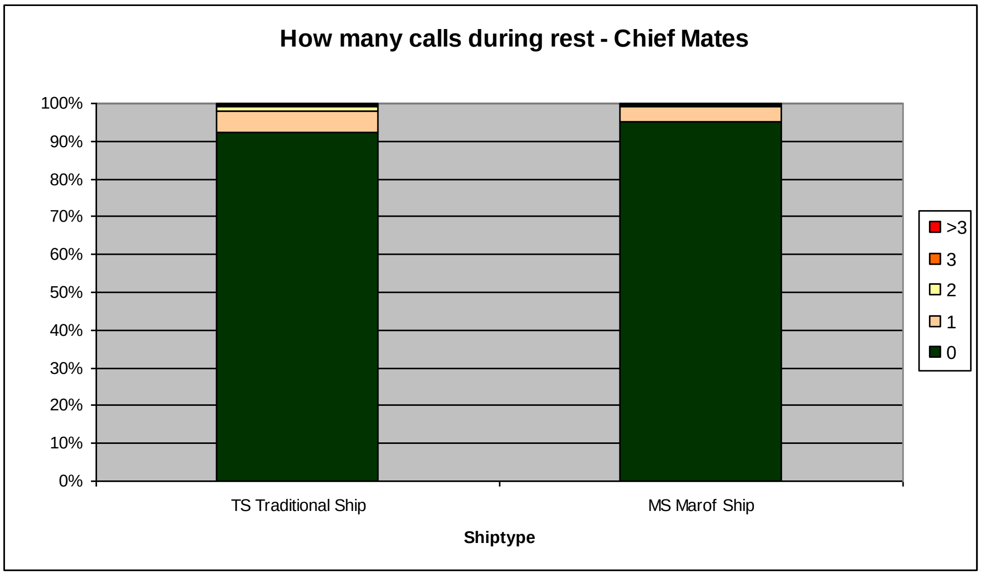


Figure 4-16 Number of times the Chief Mates are called during rest, for both types of ships.

Figure 4-17 shows that the MS Chief Mates have about the same amount of additional work to do during rest as the TS Chief Mates (6% versus 9%). For both Chief Mates, additional work consists for 4% of nautical work. The TS Chief Mate does slightly more management and paperwork (7% versus 2%), and the MS Chief Mate clearly more maintenance work (4% versus 12%) (a statistical significant difference: $\chi^2(5)=152{,}87$, $p < .001$). As is shown in Figure 4-18, the total amount of time spent on the calls and cases of additional work is for both Chief Mates in about 10% of the rest periods over one hour.

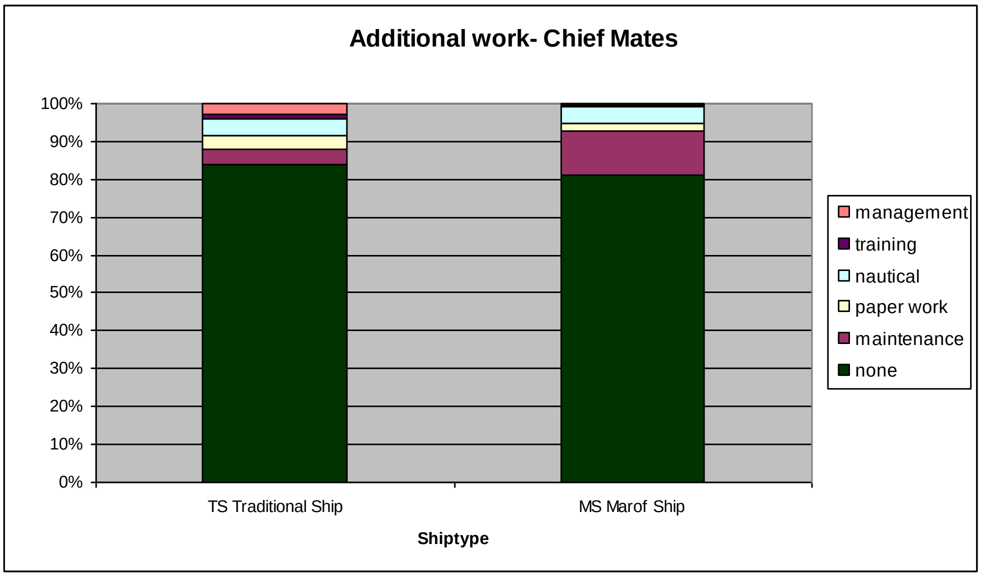


Figure 4-17 Type of additional work Chief Mates had carry out during rest, for both types of ships.

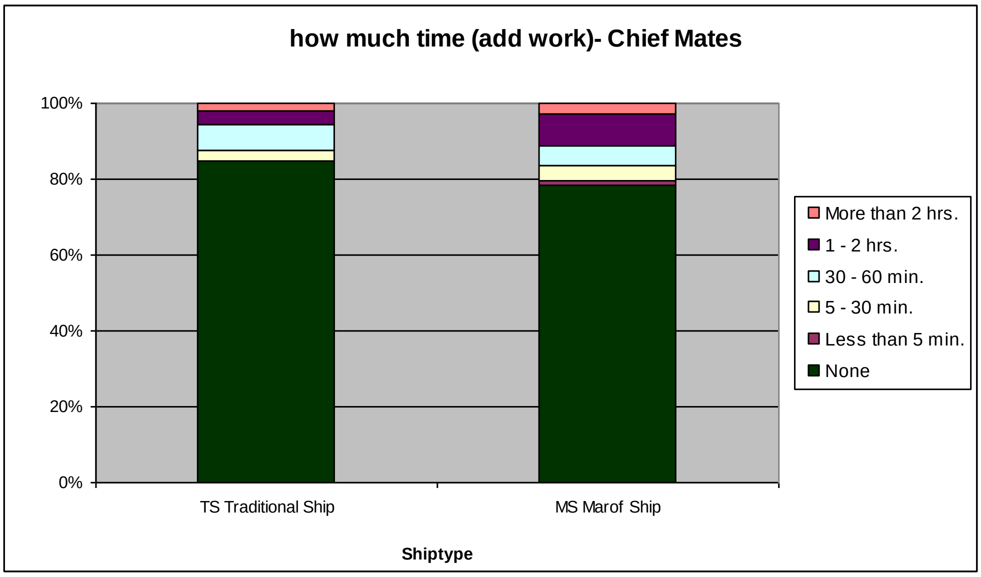


Figure 4-18 Amount of time Chief Mates spent on the calls and additional work during rest, for both types of ships.

The Marof as Mate

The results for the Marof as Mate are based on measurements on ten Marof Ships, in total 2638 shifts, and 9911 hours. In 82%, the Marof was underway, in 4% arriving/departing/piloting, in 6% moored, and in 8% anchored.

Figure 4-19 shows that, on average, the Marofs are “a little busy”. During arrival/ departure/piloting and when moored, the Marofs are slightly more busy than on average, and when under way or anchored, less busy than on average. The data show statistical significant differences between the Marofs and the other navigators (see Figure 4-2 and Figure 4-11; $F(4,38)=3,05$, $p < .05$). Post-hoc analysis shows that the Marof reports to be significantly less busy than the TS Master, the TS Chief Mate and the MS Chief Mate. There is also a significant difference found between the voyage phases. All navigators report to be more busy during Arrival-Departure-Pilot and when moored, than when under way and when anchored ($F(3,114)=44,63$, $p < .001$).

Figure 4-20 shows that the Marofs report to be “hardly tired”, in all voyage phases. Analysis on all navigators shows a difference between the Marofs and the other navigators ($F(4,38)=3,50$, $p < .05$). Post-hoc analysis shows that the Marof is statistically significant less tired than the TS Chief Mate. There is also a significant difference found between the voyage phases. All navigators report to be more tired during Arrival-Departure-Pilot and when moored than when under way or anchored ($F(3,114)=3,28$, $p < .05$).

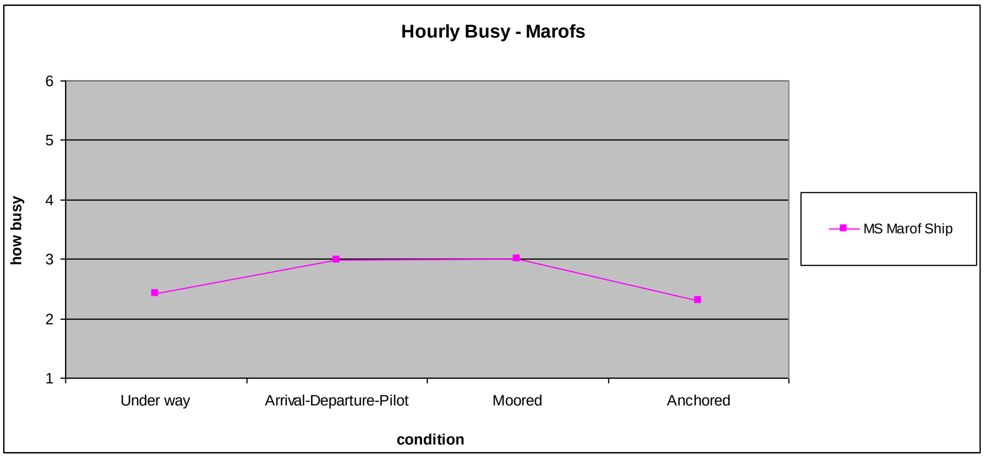


Figure 4-19 Workload of the Marofs, as measured at every hour of the watch, and shown for the four voyage phases. Score 1 = not busy at all ; 2 = hardly busy; 3 = a little busy; 4 = rather busy; 5 = considerably busy; 6 = extremely busy.

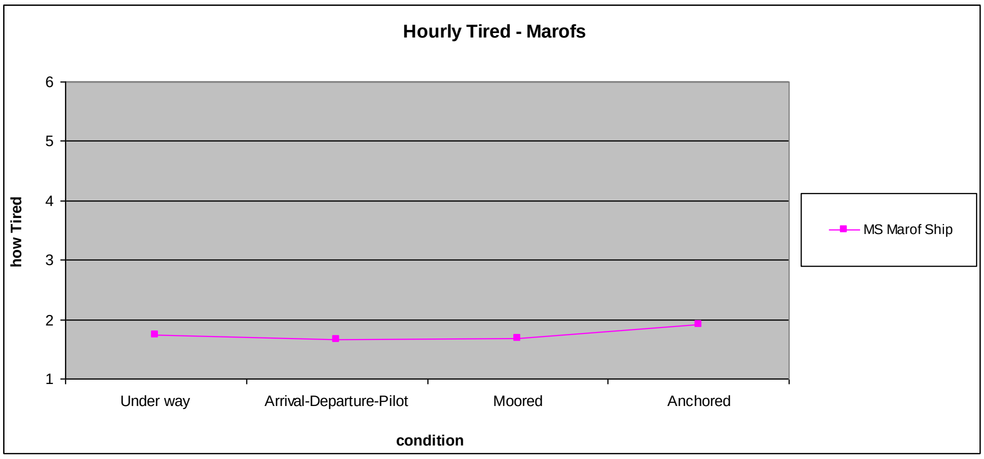


Figure 4-20 Tiredness levels of the Marofs, as measured at every hour of the watch, and shown for the four voyage phases. Score 1 = not tired at all; 2 = hardly tired; 3 = a little tired; 4 = rather tired; 5 = considerably tired; 6 = extremely tired.

Figure 4-21 illustrates the % watch hours of the Marofs, divided over the 24 hours of a day, and shown for the four voyage phases. When underway or anchored, their rest period is consistently two times four hours, from 0800 to 1200, and from 2000 to 2400. The figure may give the impression that their navigation shifts last two times eight hours. A closer look a the data reveals that the Marofs differ in when their navigation shift takes place: about half of them have their shifts from 2400 to 0400, and from 1200 until 1600, while the other half have their shifs from 0400 until 0800, and from 1600 until 2000. When moored, the Marofs skip their rest period around noon, and rest less in the evening.

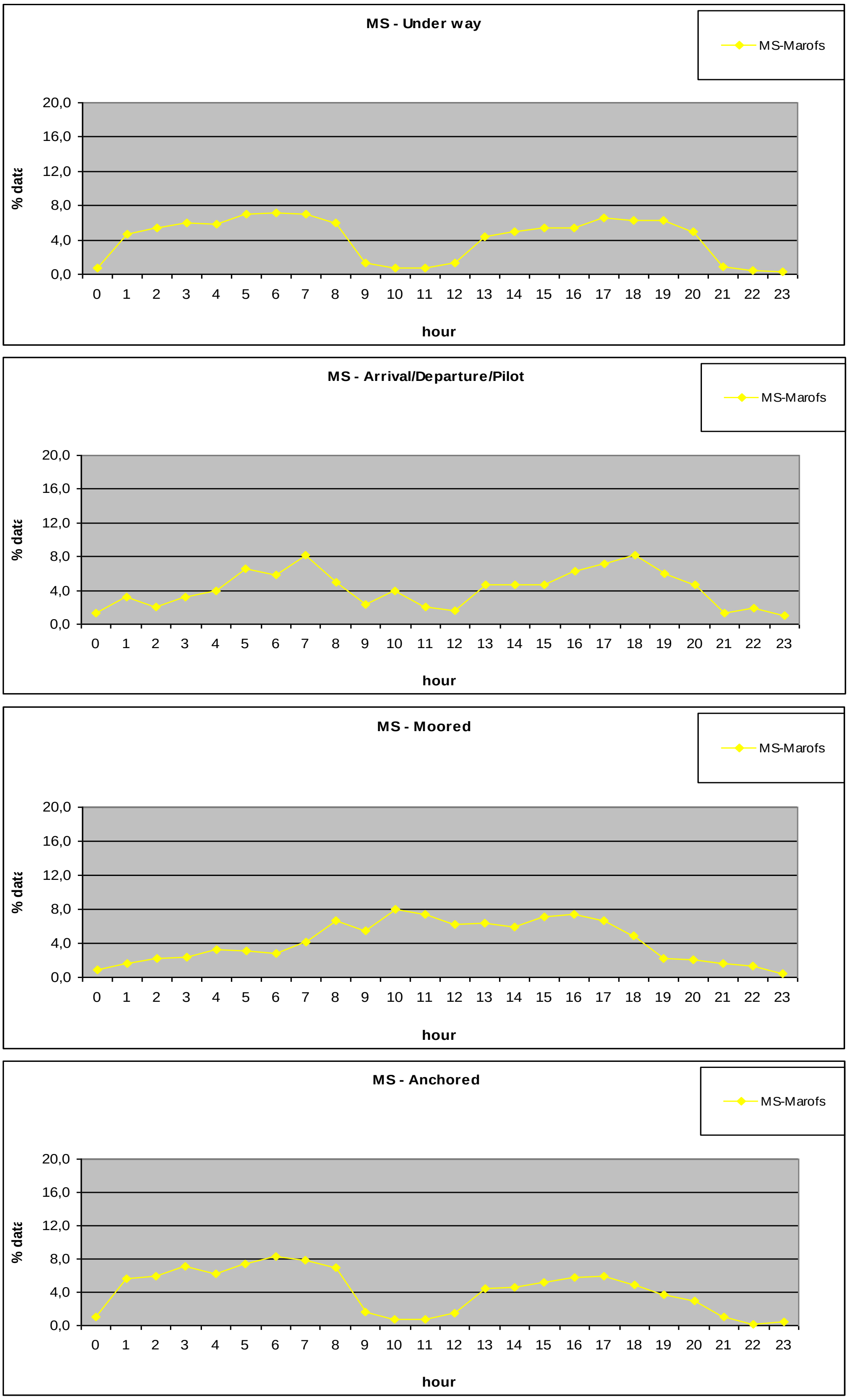


Figure 4-21 % watch hours of the Marofs, divided over the 24 hours of a day, shown for the four voyage phases.

Figure 4-22 shows the answers to the question “How many hours did you sleep?”, asked at the start of each shift. The graph shows that in about 25%, the Marof sleeps more than six hours, in 33% between four and six hours, in about 22% two to four hours, and in the remaining 20% less than two hours. The Marofs sleep significantly ore often over six hours (25%) compared to the TS Masters (10%) and the TS Chief Mates (7%) ($\chi^2(10)=705{,}99$ $p < .001$), but also significantly less often compared to the MS Masters (40%) ($\chi^2(10)=222{,}38$ $p < .001$). Compared to the MS Chief Mates (23%), they sleep about equally often over six hours (See Figure 4-5).

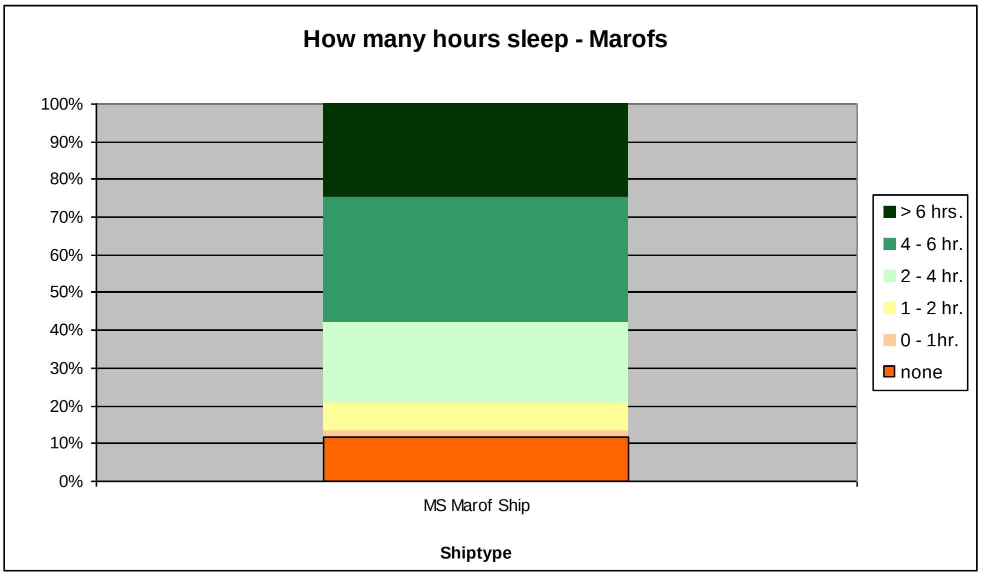


Figure 4-22 Amount of sleep of the Marofs, during the day and at night.

Figure 4-23 shows that the Marofs especially sleep over six hours when moored. This is the same for the MS Masters and TS Masters (see Figure 4-6). Also, during (or just before) arrival/departure/piloting, the Marofs sleep frequently over six hours. This is comparable to the MS Masters, but in contrast with the TS Masters (also Figure 4-6). During Anchoring, the Marofs sleep most often four to six hours. This is in contrast to the MS Masters, but comparable to the TS Masters.

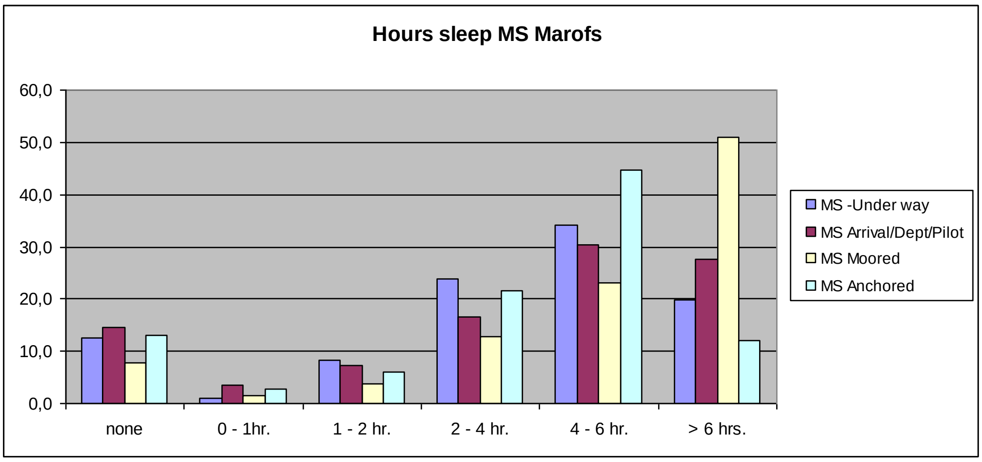


Figure 4-23 Amount of sleep of the Marofs, for the four different voyage phases.

Figure 4-24 shows the number of times the Marofs were called during rest. The Marofs were called in 11% of the shifts, compared to 7% for the TS Masters, and 13.4 % for the MS Masters (see Figure 4-7). Most of the time, the Marof was called only once. Figure 4-25 shows that the Marofs had in 23% additional work to do during rest, consisting mainly of maintenance (16%) and nautical work (5%). Figure 4-26 shows that in 11% of the rest periods, the amount of time spent on additional work was over one hour. This is comparable to the Chief Mate.

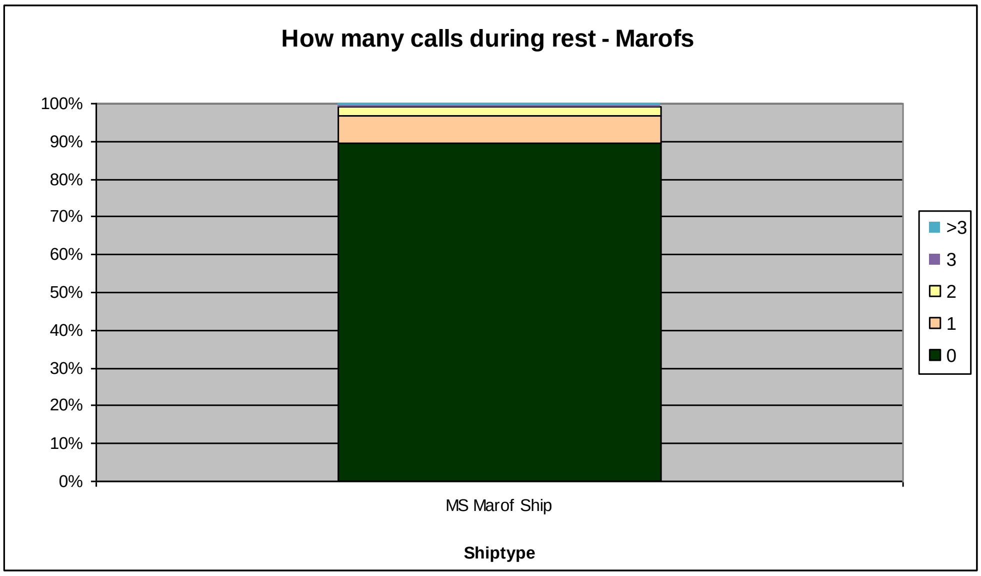


Figure 4-24 Number of times Marofs were called during rest.

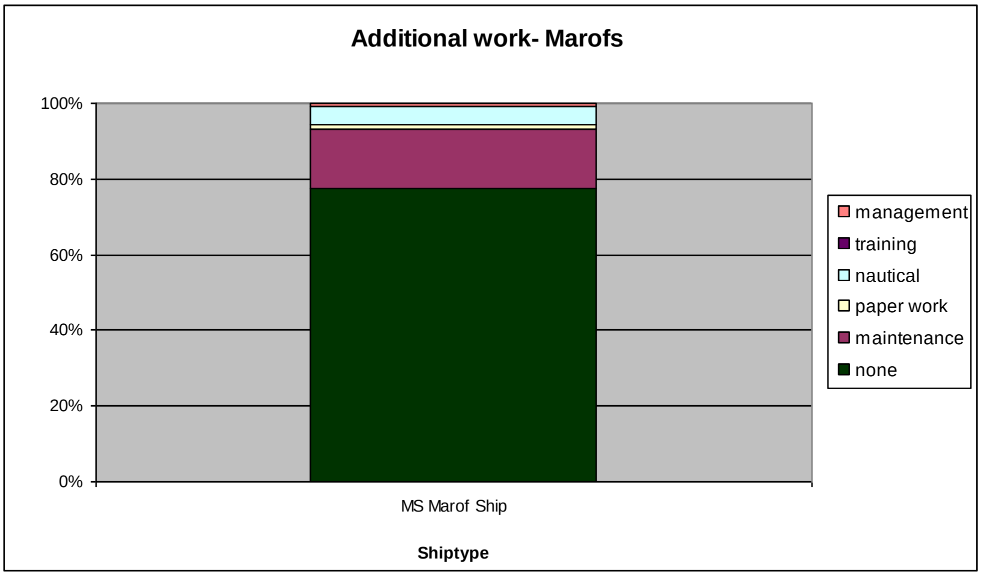


Figure 4-25 Type of additional work Marofs had to perform during rest.

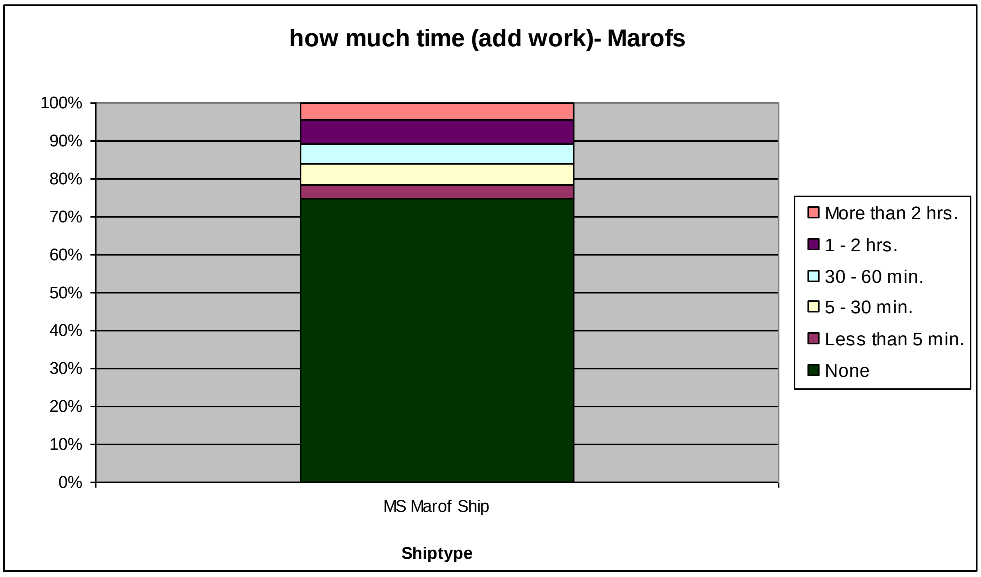


Figure 4-26 Amount time spent on the calls and additional work the Marofs had to do during rest.

Concluding remarks

The comparison between the crews on the Traditional ships and the Marof ships shows that all navigators report to be “a little busy”, on average (see Figure 4-27). Overall, the navigators report low tiredness levels, which are less than “a little tired’, but the navigators on Marof ships report to be 20% less tired than the navigators on Traditional ships (see Figure 4-28). The crews report to be more busy and more tired during arrival / departure / piloting and when moored, compared to when they are underway or anchored.

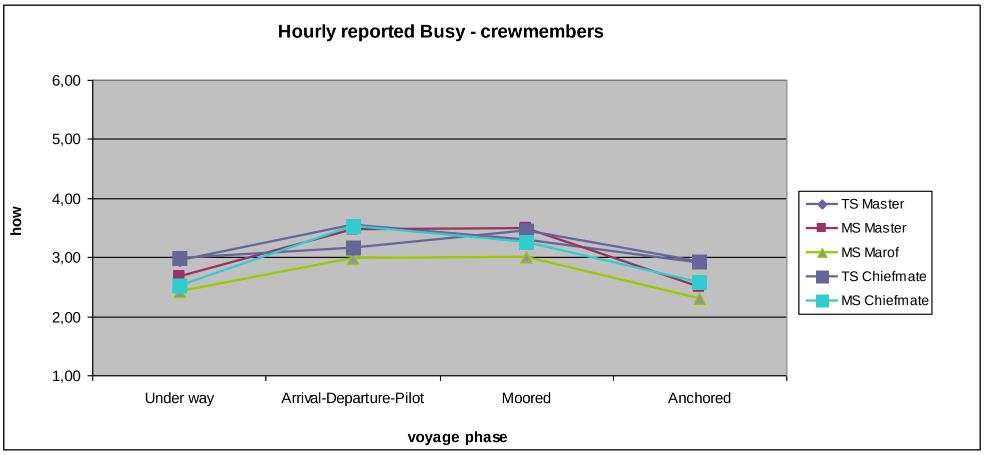


Figure 4-27 Workload of all navigators on the Traditional and Marof ships, as measured at every hour of the watch, and shown for the four voyage phases. Score 1 = not busy at all ; 2 = hardly busy; 3 = a little busy; 4 = rather busy; 5 = considerably busy; 6 = extremely busy.

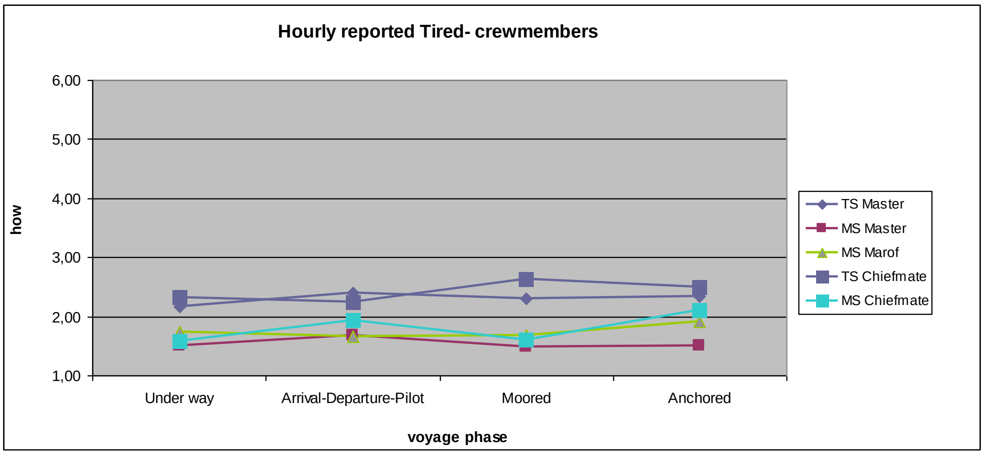


Figure 4-28 Tiredness levels of the navigators on the Traditional and Marof ships, as measured at every hour of the watch, and shown for the four voyage phases. Score 1 = not tired at all ; 2 = hardly tired; 3 = a little tired; 4 = rather tired; 5 = considerably tired; 6 = extremely tired.

Further, the crews on the Marof ships report to sleep more often over six hours, compared to the crew on the Traditional ships. Crew on Traditional ships only sleep over six hours when moored. Finally, crews on the Marof ships have, on average, shorter shifts.

4.2.2 Engineering activities

The Chief Engineer

The results for the Chief Engineers are based on measurements on seven Traditional Ships, in total 2066 shifts. Two other Traditional Ships of the nine that participated were excluded due to the low number of measured shifts.

At the start of each shift, the Chief Engineers were asked three questions: about their rest period, the current voyage phase, expected work load and current tiredness level. In contrast to the Master, the Chief Mate and the Marof as Mate, the Chief Engineer and the Marof as Engineer were not measured every hour.

Overall, the Chief Engineer sleeps in 63% of the time more than six hours, and in 28% of the time four to six hours. They have a regular sleeping rhythm over the different voyage phases (see Figure 4-29).

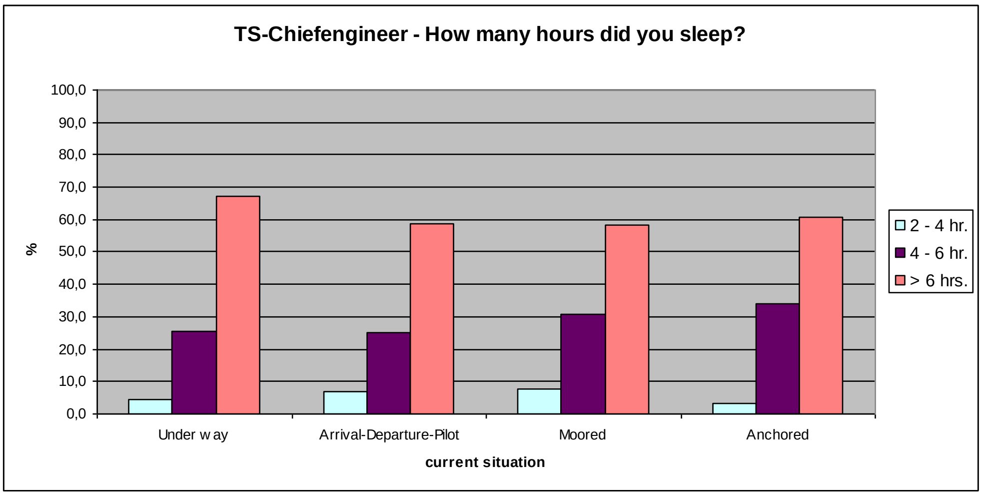


Figure 4-29 Number of hours the Chief Engineer sleeps, for the four voyage phases.

In 28% of their rest periods, they were called for assistance. In 44% of their rest periods, they had to do maintenance (24%), paperwork (16%), or nautical work (4%). In 33% of the cases this took less than 30 minutes, in 32% 30-60 minutes, and in 35% a significant amount of time (more than one hour) (see Figure 4-30).

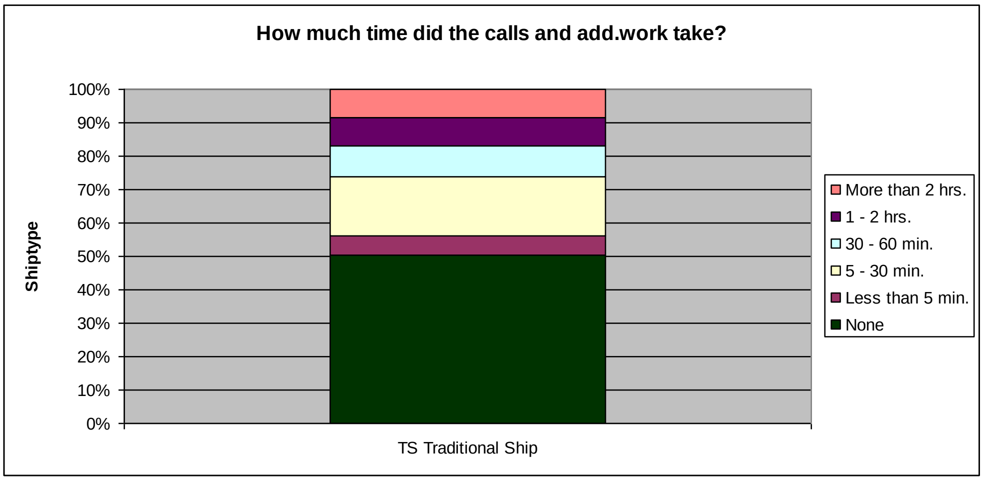


Figure 4-30 Amount of time additional work, including calls for assistance, took for Chief Engineers, during rest.

The Chief Engineers report at the start of the shift, in 40% to be “a little tired” or more tired than that.

After each shift, the Chief Engineers were asked questions about how busy and tired they were. For all four voyage phases, they judged how busy they were as in between “a little busy” and “rather busy” (Figure 4-31), and how tired they were as in between “a little tired” and “rather tired” (Figure 4-32).

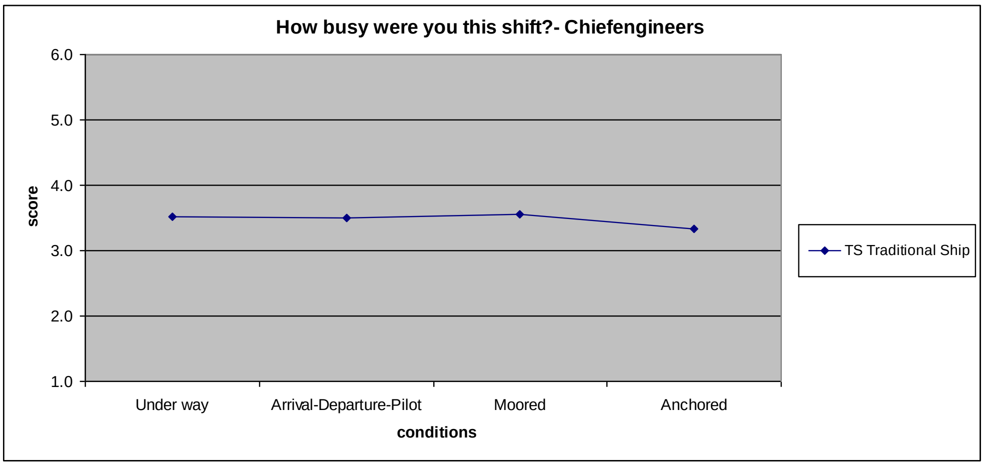


Figure 4-31 Judgment by the Chief Engineer of how busy he was, for the four voyage phases. 1: not busy at all; 2: hardly busy; 3: a little busy: 4: rather busy; 5: considerably busy; 6: extremely busy.

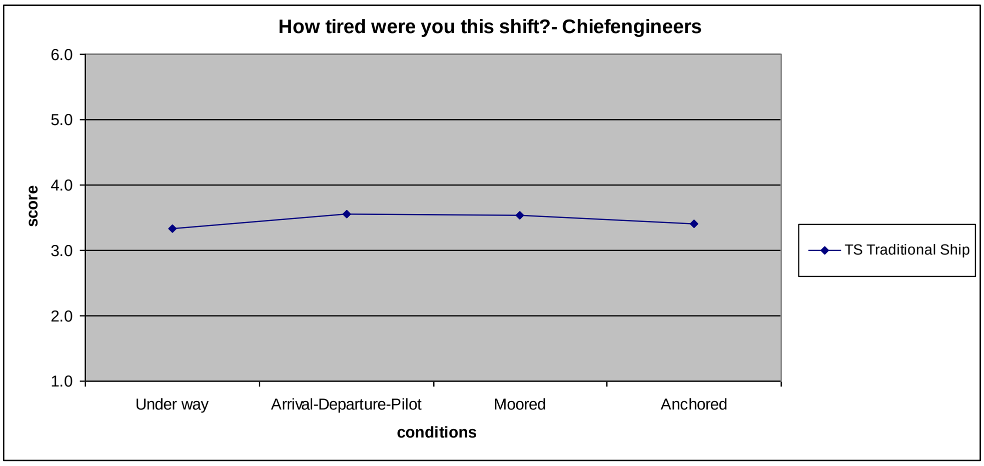


Figure 4-32 Judgment by the Chief Engineer of how tired he was, for the four voyage phases. 1: not tired at all; 2: hardly tired; 3: a little tired: 4: rather tired; 5: considerably tired; 6: extremely tired.

The Marof as Engineer

The results for the Marof as Engineer are based on measurements on ten Marof Ships, in total 867 shifts.

As is shown earlier in Figure 4-22, the Marofs sleep in 25% over six hours, and in 35% between four and six hours, compared to 63% resp. 28% for the Chief Engineers (see the previous subsection). The Marofs report, at the start of the shifts, in 14% to be “a little tired” or more tired than that, while the Chief Engineers report in 40% of the shifts to be “a little tired” or more.

The next two figures show how busy the Marof as Engineer was during the four voyage phases: in between “a little busy” and “rather busy” (Figure 4-33), and how tired they were as in between “hardly tired” and “a little tired” (Figure 4-34). Compared to the Chief Engineer, the Marof Engineer is equally busy ($F(1,14)=1,75$, n.s.), but significantly less tired ($F(1,14)=27,19$, $p < .001$).

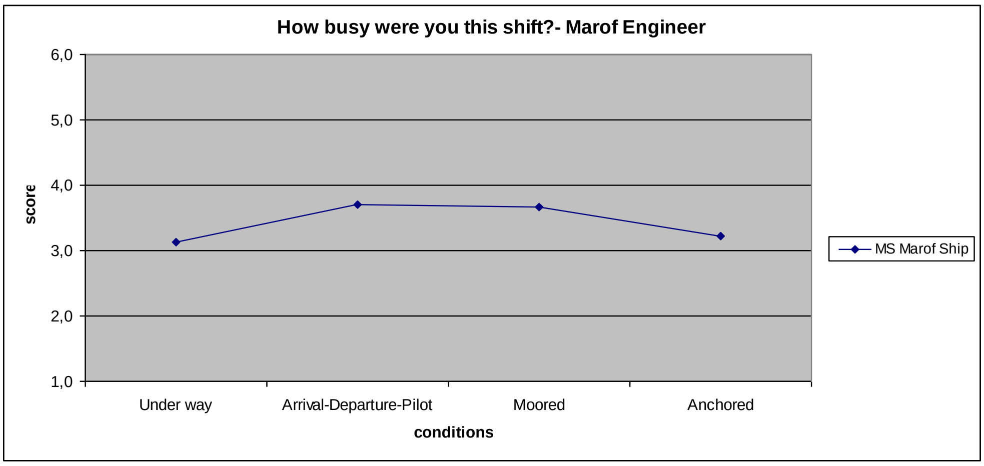


Figure 4-33 Judgment by the Marof as Engineer of how busy he was, for the four voyage phases. 1: not busy at all; 2: hardly busy; 3: a little busy: 4: rather busy; 5: considerably busy; 6: extremely busy.

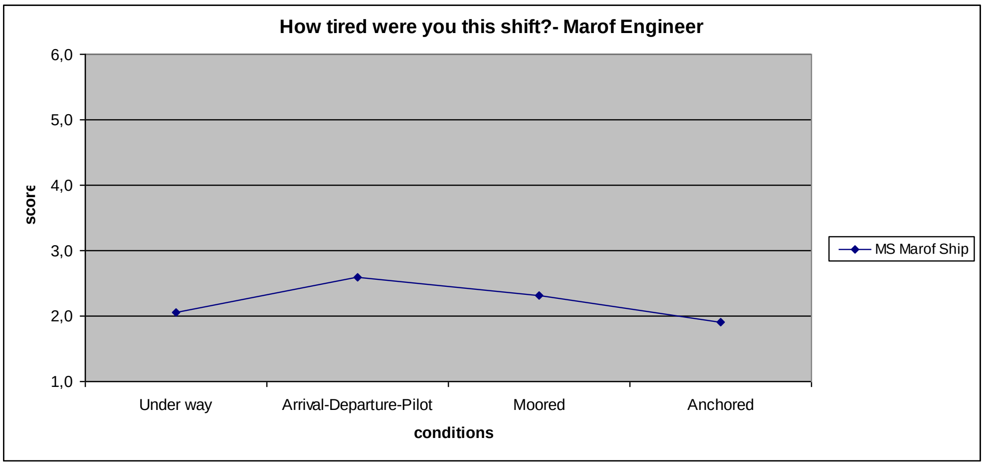


Figure 4-34 Judgment by the Marof as Engineer of how tired he was, for the four voyage phases. 1: not tired at all; 2: hardly tired; 3: a little tired: 4: rather tired; 5: considerably tired; 6: extremely tired.

Concluding remarks

In contrast to the Marofs as Engineer, the Chief Engineers have a regular sleeping rhythm over the different voyage phases. They sleep much more often over six hours. Chief Engineers start their shifts more tired compared to Marofs: they report in 40% to be “a little tired” or more, whereas the Marofs as Engineers report this in 14%. After their engineering shifts, Chief Engineers and Marofs report their shifts to be equally busy, but Chief Engineers report to be 20% more tired (between “little tired” and “rather tired”).

4.2.3 Team support & Distribution of Work

Figure 4-35 illustrates the % watch hours of the MS Masters, the MS Chief Mates and the Marofs, divided over the 24 hours of a day, and shown for the four voyage phases. It shows that the Marofs and the Chief Mates complement the Masters, when underway and when anchored. During arrival/departure/piloting and when moored, the crew frequently have their shifts outside their usual schedule. Arriving/departing/piloting can take place any time. When moored, most activities take place during the day.

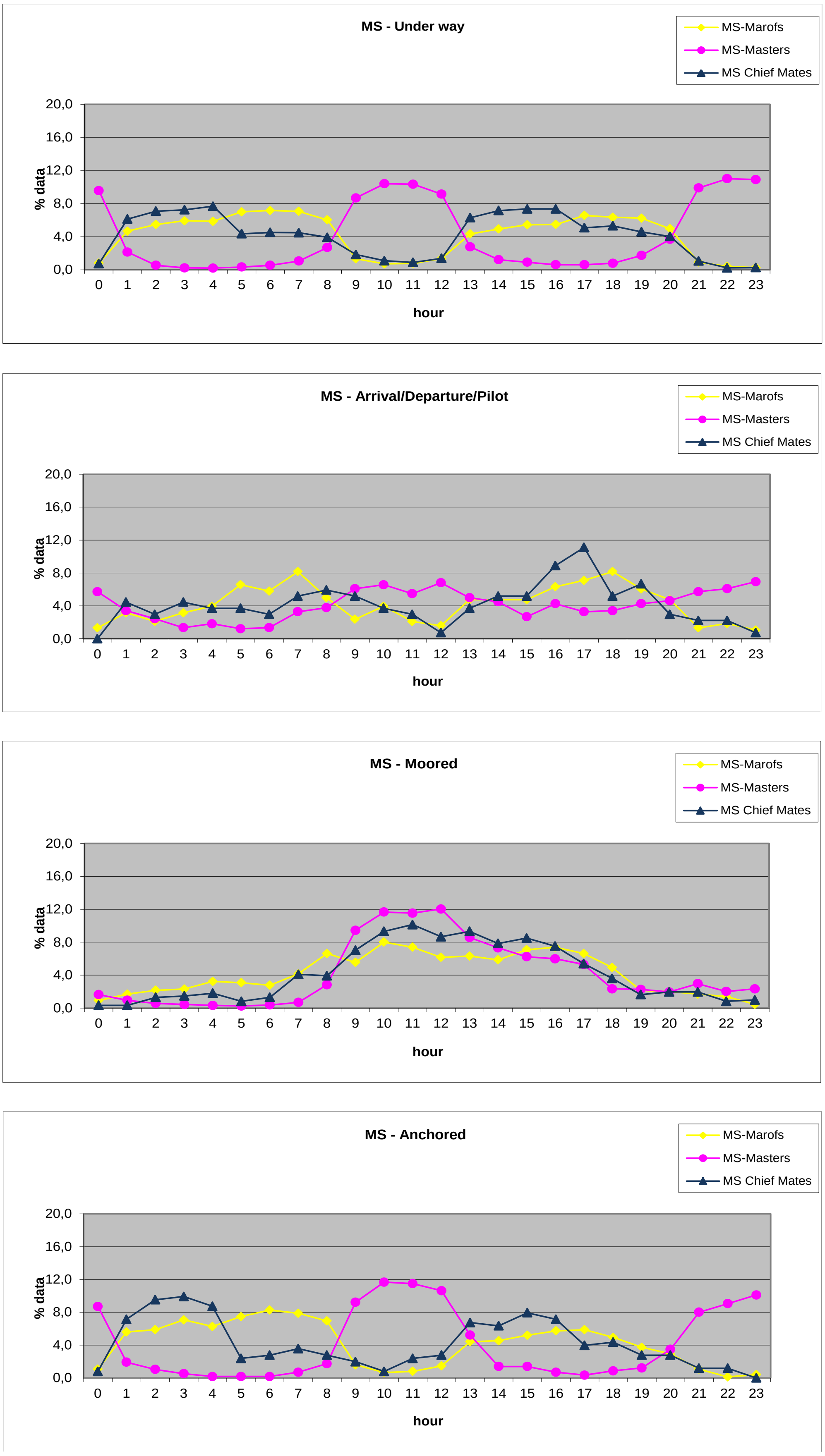


Figure 4-35 % watch hours of the Masters, the Chief Mates and the Marofs on the Marof Ships, divided over the 24 hours of a day, shown for the four voyage phases.

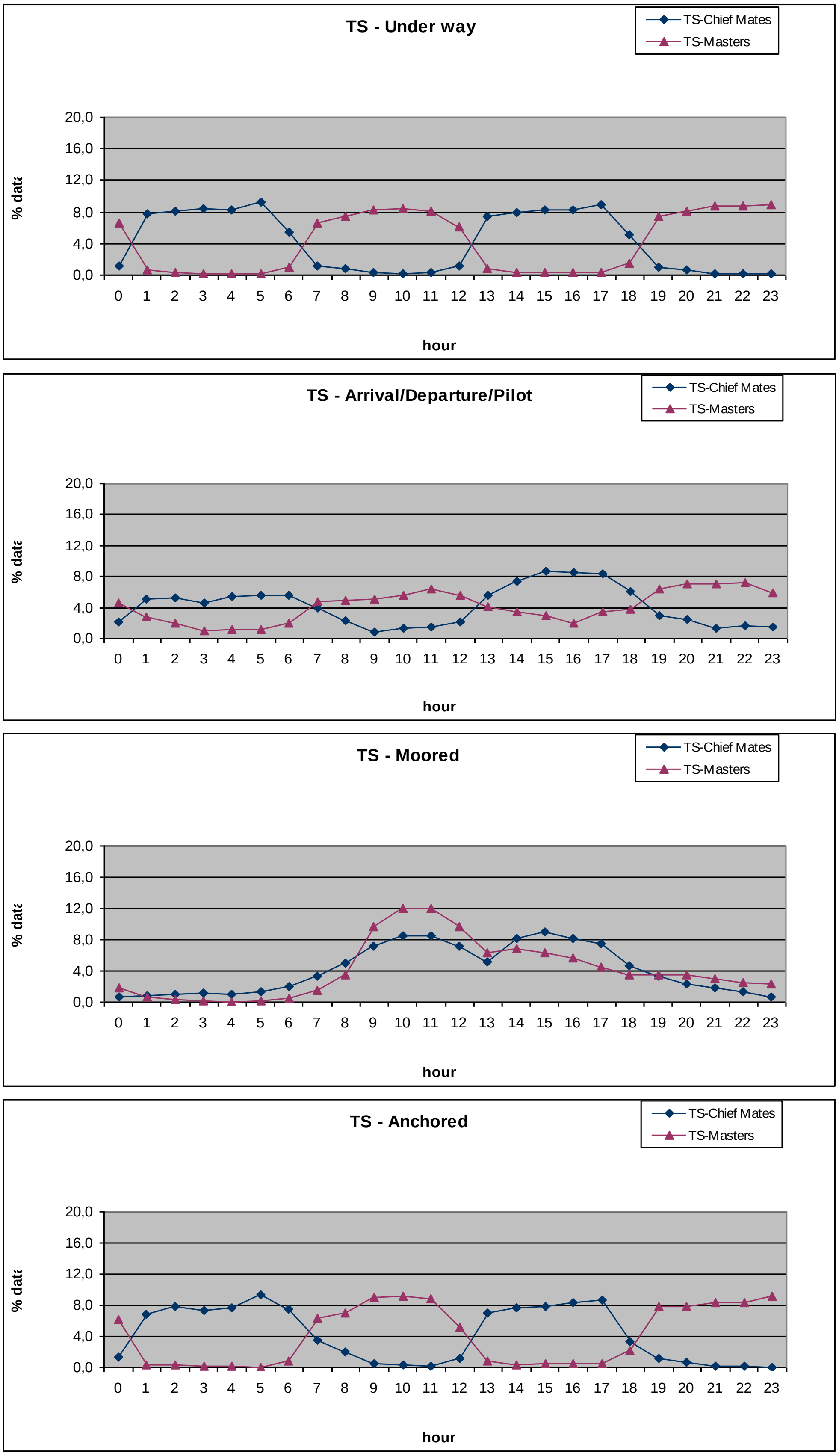


Figure 4-36 % watch hours of the Masters and the Chief Mates on the Traditional ships, divided over the 24 hours of a day, shown for the four voyage phases.

Figure 4-36 illustrates the % watch hours of the TS Masters and TS Chief Mates, divided over the 24 hours of a day, and shown for the four voyage phases. It shows that the Chief Mates complement the Masters, when underway, during arrival/departure/piloting and when anchored. When moored, the Master and Chief Mate work at the same time. Arriving/departing/piloting can take place any time. When moored, most activities take place during the day.

Table 4-4 shows the distribution of the shifts over the voyage phases, for both Marof roles. It shows that, when underway, the Marof carries out much more often the role of Mate and much less the role of Engineer, while when moored, the Marof takes far more often the role of Engineer and far less often the role of Mate.

Table 4-4 The distribution of the shifs of the Marof over the voyage phases, for both roles.

Role	**Under way**	**Arrival/ Departure/Pilot**	**Moored**	**Anchored**	**Total**
Mate	2160 (82%)	131 (5%)	134 (5%)	206 (8%)	2631 *(75%)*
Engineer	338 (39%)	79 (9%)	420 (48%)	30 (4%)	867 *(25%)*
Total	*2289 (71%)*	*210 (6%)*	*554 (16%)*	*236 (7%)*	*3498*

In our interviews with Traditional crews we noticed resentment about the fact the work load was not equally distributed, especially during periods of heavy work load, such as when moored.

4.2.4 Shore Support

After each voyage, the Masters were asked to indicate their satisfaction with shore support. The Marof Ships needed shore support more often than Traditional ships (28% versus 15% of all 311 voyages; $\chi^2(1)=7{,}75$,p < .05) (see Figure 4-37).
If needed, the TS Master was most often “very satisfied” (24%) or “satisfied” (64%) with Shore Support. In 12% (3 times), the master was “unsatisfied” or “very unsatisfied”. The MS Master was also most often “very satisfied” (14%) or “satisfied” (69%) with Shore Support, and in 17% (6 times), “unsatisfied” or “very unsatisfied”. These differences in satisfaction was not found to be significant ($\chi^2(2)=<1$, n.s.).

Figure 4-37 Satisfaction of Masters with shore support.

The Chief Engineer and the Marof as Engineer were also asked about Shore Support, but much more frequently, after each shift. The Marof needed Shore Support statistically significant more often than the Chief Engineer ($\chi2(1)=4,05$, $p<.05$): 6.8% (20 times) versus 3.7% (34 times) of their shifts. If needed, the Marof was most often “very satisfied” (25%) or “satisfied” (56%) with Shore Support, and less often “unsatisfied” (19%). In contrast, the Chief Engineers, when they needed shore support, were more often “unsatisfied” (50%), or even “very unsatisfied” (3%) than “satisfied” (47%). They were never “very satisfied” (see Figure 4-38).

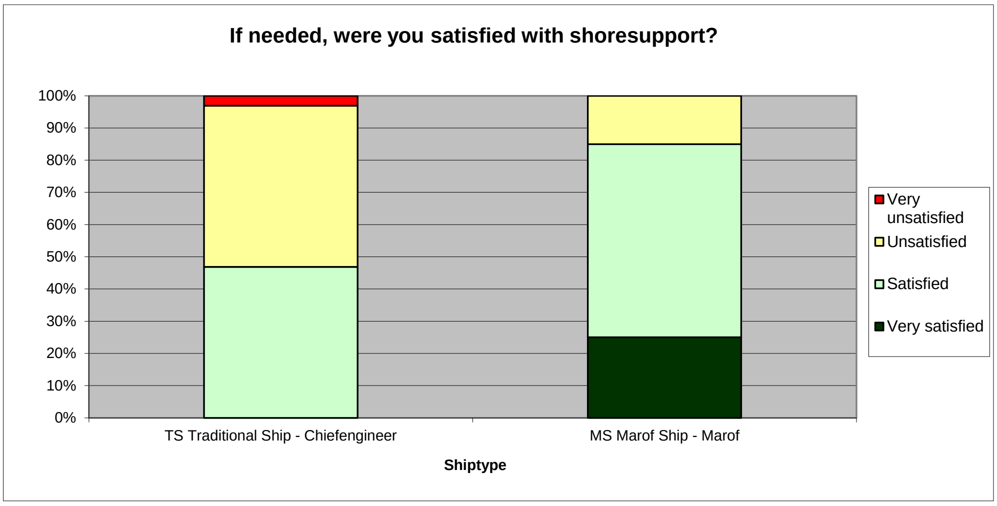


Figure 4-38 Satisfaction with Shore Support, when needed, judged by the Marof (right) and the Chief Engineer (left).

The interviews with the shore support organisation personnel and the crews, and the questionnaires filled out by (a part of) the crew, indicated that there are large individual differences, but overall, Chief Engineers on shortsea ships have deeper technical knowledge, better repair skills, and do more pro-active maintenance, compared to Marofs. However, compared to Marofs, they more often lack cooperative and interactive troubleshooting skills, due to language difficulties and cultural differences.

4.3 The outcome

In this section, the outcome of all processes are described, in terms safe sailing, work satisfaction and atmosphere, technical functioning and realized maintenance.

4.3.1 Safe sailing

The Master

At the end of each shift, the Masters were asked a couple of questions about their shift. A total of 5940 shifts were judged (64% TS, 36% MS).
Figure 4-39 shows that MS Masters are more positive on how the shift went compared to the TS Masters (A statistical significant difference. ANOVA on aggregated data: $F(1,15)=4,99$, $p < .05$). Compared to the TS Masters, MS Masters more often assessed their shift as ‘Very well’ (36% for MS, 9% for TS). Also, MS Masters assessed their shift more often as either “Very well” or “Pretty well” (72% versus 56%). Less than acceptable shifts do happen as well: 1.5% of the TS shifts versus 4.2% of the MS shifts.

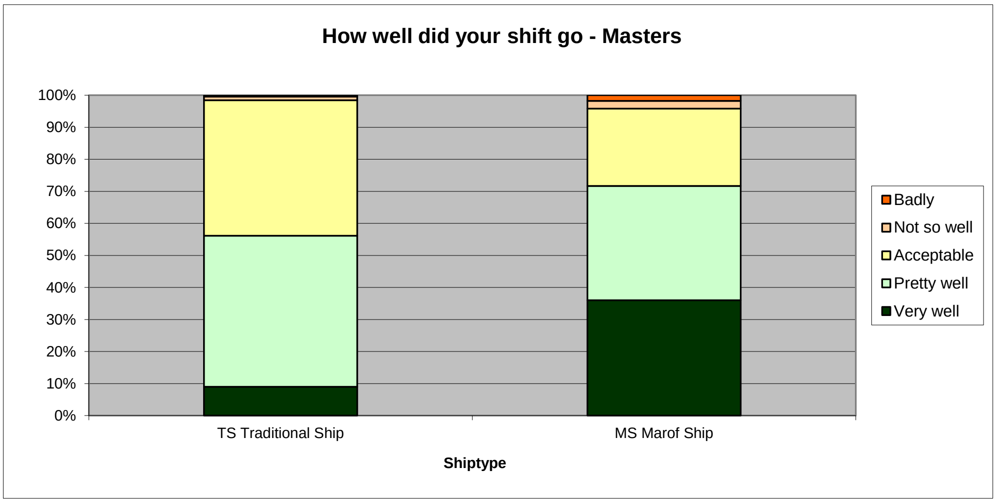


Figure 4-39 Assessments by the masters of how well their shifts went, for the different types of ships.

At the end of each shift, the Master was asked whether a critical situation had happened. For the TS Masters, a critical situation took place, on average, 6.6 times every 1000 hours, and for the MS Masters 5.9 times. Figure 4-40 shows that Arrival/departure/pilot is the most critical voyage phase. No difference is shown in distribution between the Traditional ships and the Marof ships, over the four voyage phases, but for all phases, the MS Masters report fewer critical situations compared to the TS Masters. This difference was, however, not found to be statistically significant (Fisher's exact test; $\chi^2(1)=3{,}02$, p =.08).

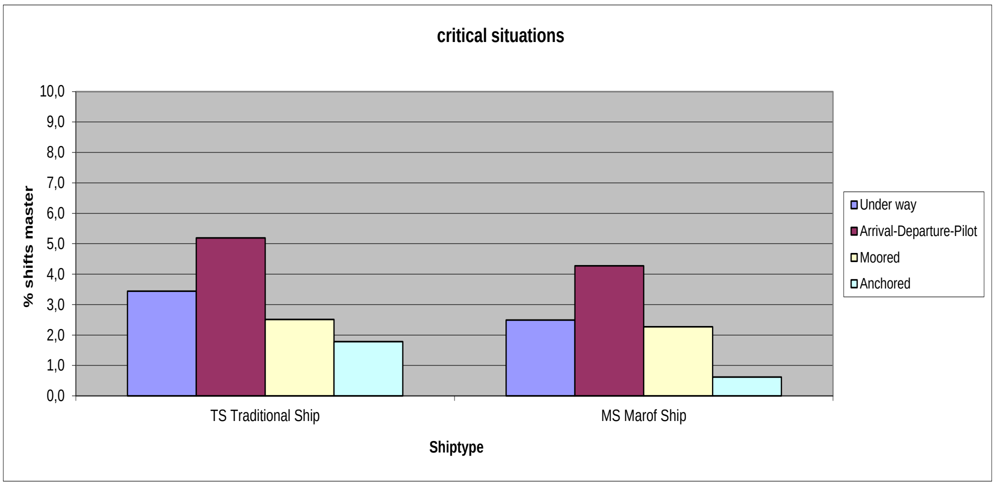


Figure 4-40 Percentage of reported critical situations per voyage phase, as reported by the Masters, and for the different types of ships.

The Chief Mate

At the end of each shift, the Chief Mates were asked a couple of questions about the shift. A total of 4784 shifts were judged (73% TS, 27% MS). Figure 4-41 shows that MS Chief Mates more often assessed their shift as ‘Very well’ (31% for MS, 13% for TS). Also, MS Chief Mates assessed their shift more often as either “Very well” or “Pretty well” (72% versus 35%). Less than acceptable shifts happen equally often: 2.5% of the MS shifts versus 2.3% of the TS shifts. This difference was, however, not found to be statistical significant (F1,14)=1.2, n.s.)

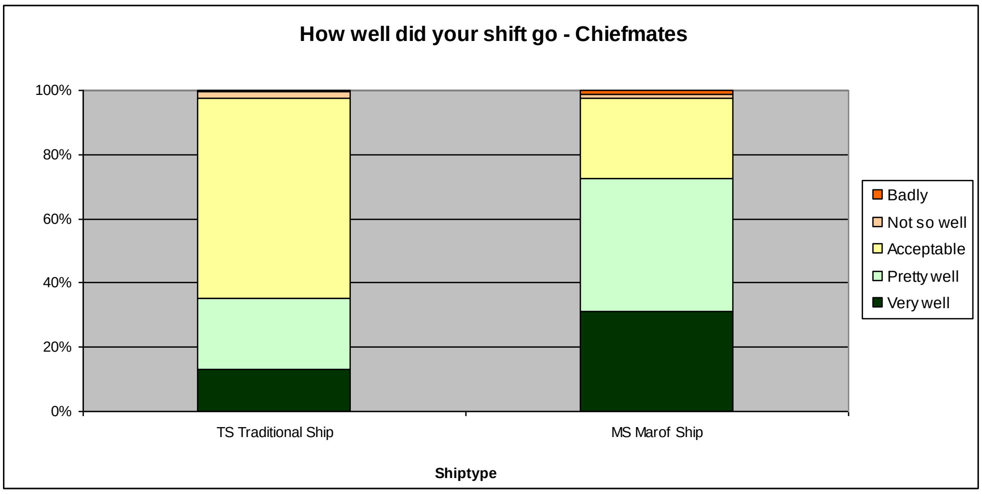


Figure 4-41 Assessments by the Chief Mates of how well their shifts went.

At the end of each shift, the Chief Mates were also asked whether a critical situation had occurred. For TS Chief Mates, a critical situation took place, on average, 5.1 times every 1000 hours, and for the MS Chief Mates 4.8 times.

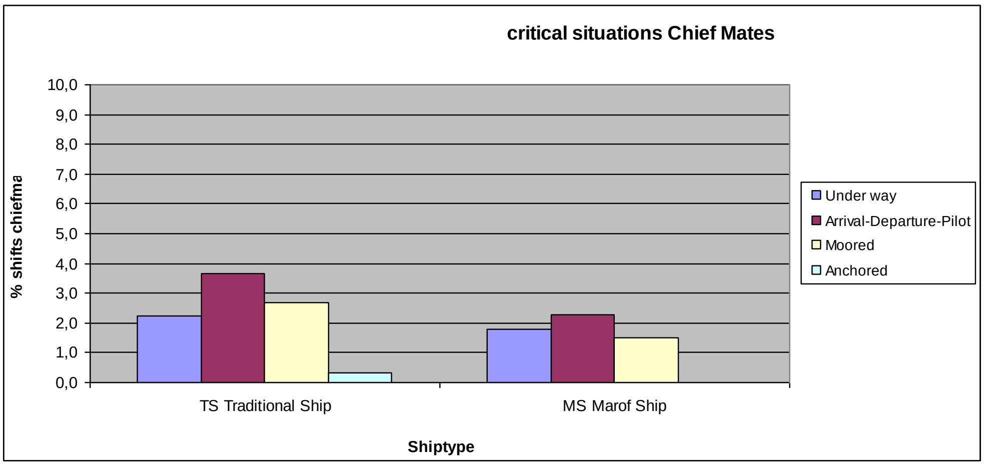


Figure 4-42 Percentage of reported critical situations per voyage phase, as reported by the Chief Mates, for the different types of ships.

The Marof as Mate

Figure 4-43 shows that the Marofs assessed their shifts in 23% of the cases as ‘Very well’ (36% for MS Master, 31% for the MS Chief Mate; 9% for TS Master, 13% for the TS Chief Mate. See Figure 4-39 and Figure 4-41). They assessed in 69% of the cases their shift as either “Very well” or “Pretty well” (72% for MS Master, 72% for the MS ChiefMate; 56% for TS Master, 35% for the TS Chief Mate). Less than acceptable shifts happen in 5% of the shifts (4.2% for the MS Masters, 2.5% for the MS Chief Mates; 1.5% for the TS Masters, 2.3% for the TS Chief Mates).

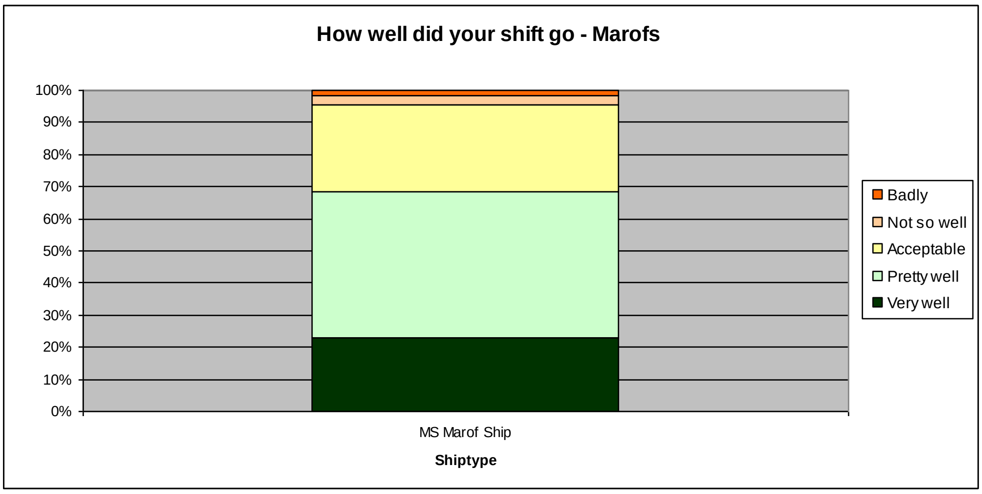


Figure 4-43 Assessments by the Marofs as Mate of how well their shifts went.

For the Marofs, a critical situation took place, on average, 6.2 times every 1000 hours. Figure 4-44 shows that arrival/departure/pilot is the most critical voyage phase. No difference is shown in distribution between the traditional ships and the marof ships, over the four voyage phases, but for all phases, the Marofs report fewer critical situations compared to the TS Masters and about the same as the MS Masters (see Figure 4-40).

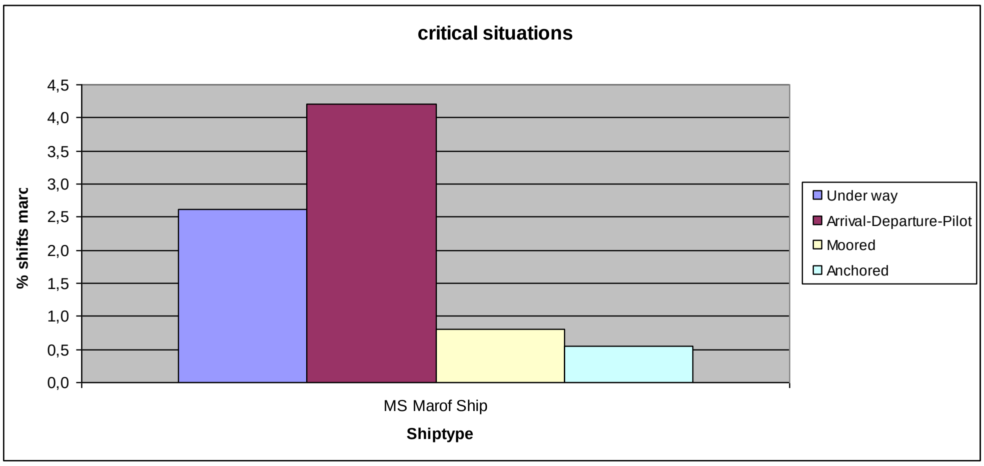


Figure 4-44 Percentage of reported critical situations per voyage phase, as reported by the Marofs.

Concluding remarks

Overall, navigation shifts on Marof ships went better, compared to Traditional ships. Analysis on all Officers shows a statistical significant difference between how well they reported their shifts ($F(1,46)=14,64$, $p < .001$).

Table 4-5 shows an overview of the reported critical situations. It shows that on average, all crew members have a comparable incidence: about 6 critical situations per 1000 hours, which is roughly once every voyage. All comparisons were made, no statistical difference was found ($\chi2(1)=<1$, n.s.).

Table 4-5 Overview of the crew members, their watch hours, their reported number of critical situations and their incidence (cases per 1000 hours).

	Traditional Crews		Marof Crews			Total
	Master	Chief Mate	Master	Chief Mate	Marof	
Watch Hours	18896	15628	9223	3782	9911	57440
Critical situations	125	79	54	18	61	337
Incidence (1000hrs)	6.62	5.06	5.85	4.76	6.15	5.87

Table 4-6 shows the critical situations and incidence for both types of crews, and the reported categories. No statistical significant difference in overall critical situations has been found for Traditional crews and Marof crews (χ2(1)=<1 , n.s.). For the individual categories, bad weather critical situations occurred more often on Marof Ships ($\chi^2(1)=5,67$, $p < .05$); for the four other categories, no significant difference was found (χ2(1)=<1 , n.s.). The table further shows that critical navigational situations occur most often (49% of the cases; about once every two voyages;), followed by bad weather situations (23%; about once every four voyages), and critical technical situations (15%; about once every six/seven voyages). Critical situations related to personnel happen about once every 1.5 year (8%); cargo every 3 year (4%).

Table 4-6 Overview of the crews, their watch hours, their reported number of critical situations in categories and their incidence (cases per 1000 hours).

	Traditional Crews		Marof Crews		Total Crews	
Watch Hours	34524		22916		57440	
	Cases	**Incidence**	**Cases**	**Incidence**	**Cases**	**Incidence**
Critical Situation	204	5.91	133	5.80	337	5.87
Bad weather	29	0,84	36	1,57	65	1,13
Navigational	87	2,52	49	2,14	136	2,37
Technical	22	0,64	21	0,92	43	0,75
Personnel	12	0,35	10	0,44	22	0,38
Cargo	9	0,26	3	0,13	12	0,21

4.3.2 Realized maintenance

After each shift, the Chief Engineers and Marofs were asked a question about how well their shift went. Marofs report their shifts as better than Chief Engineers (a statistical significant difference: (F1,14)=9,36, $p < .01$. See Figure 4-45.). In 69% of all shifts, the Marof judged the Engineering shift as “pretty well” (54%) to “very well” (19%), whereas the Chief Engineer judged these categories 12% resp. 2%. Both judged 4% of their shifts as less than acceptable.

For all four voyage phases, the shifts went “pretty well”, on average; during arrival/departure/pilot, the shift went somewhat less well than that, on average.

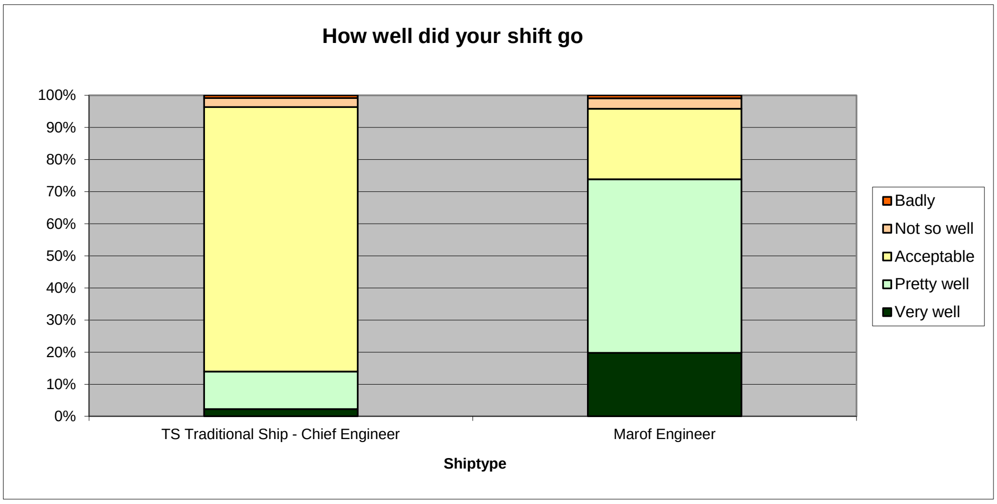


Figure 4-45 Judgments by the Marof as Engineer (right) and Chief Engineer (left) on how well the shift went.

The Marof Engineer and Chief Engineer follow a scheduled maintenance program. Figure 4-46 shows how well the Chief Engineers and the Marofs could keep up with their planned work, during their shift. The Chief Engineers could keep up better. Only in 2% of their shifts, they were behind schedule, whereas the Marofs were in 7% of their shifts behind schedule. On the other hand, the Marofs were more often ahead of schedule: in 5% of their shifts, whereas the Chief Engineers were only in 1% of their shifts ahead of schedule.

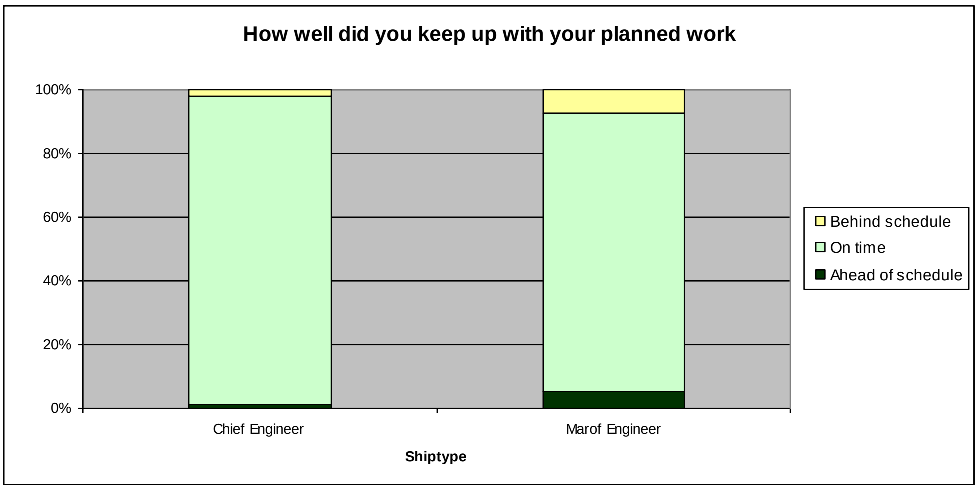
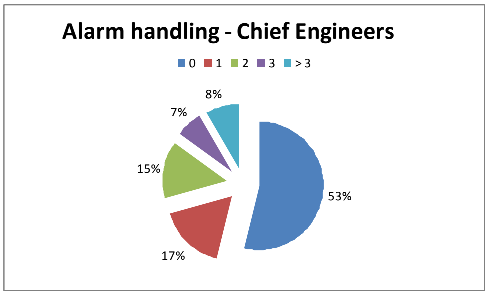


Figure 4-46 Judgments by the Chief Engineers (left) and the Marofs as Engineers (right) on how well they could keep up with their planned work.

4.3.3 *Technical functioning*

Only modern ships, not older than 10 years, participated in this study. After each shift, the Chief Engineers and Marofs as Engineer were asked whether they had to handle any alarms during their rest and their shift (see Figure 4-47).
Alarms occurred approximately every two days. Chief engineers had to handle slightly more often alarms (47%), compared to Marofs (39%). When there was an alarm, they had to handle in most cases multiple alarms that day.



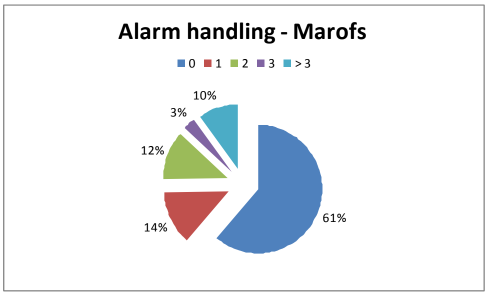


Figure 4-47 The number of alarms the Chief Engineers (left) and the Marofs (right) had to handle during their rest and engineering shift.

Table 4-5 shows the reported number of critical situations that were classified as technical failure: 43 cases. The incidence of technical failure (cases every 1000 hours) is lower for the Traditional crews (TS Master: 0.7; TS Chief Mate: 0.5) compared to the Marof crews (MS Master: 1.0; MS Chief Mate: 1.1; Marof: 0.8). No statistically significant difference was found between Marof crews and Traditional crews ($\chi 2(1)=<1$, n.s.). Not a single reported critical situation has been classified as both technical and navigational.

A comparison between the two types of ships of the number of alarms to be handled as well as the number of reported critical situations classified as technical failures does not indicate a difference in technical functioning.

4.3.4 Work Satisfaction and Atmosphere

After each shift, all Officers were asked how well their shift went. We consider this is also as an indication of their work satisfaction. Figure 4-39, Figure 4-41 and Figure 4-45 all indicate that at Marof ships, the shifts went more satisfactory than on Traditional ships.

Figure 4-48 shows the comparison between the Marof as Engineer and as Mate, on how well both shifts went. The work satisfaction in both shifts are roughly the same. Figure 4-49 shows the judgments over the four voyage phases.

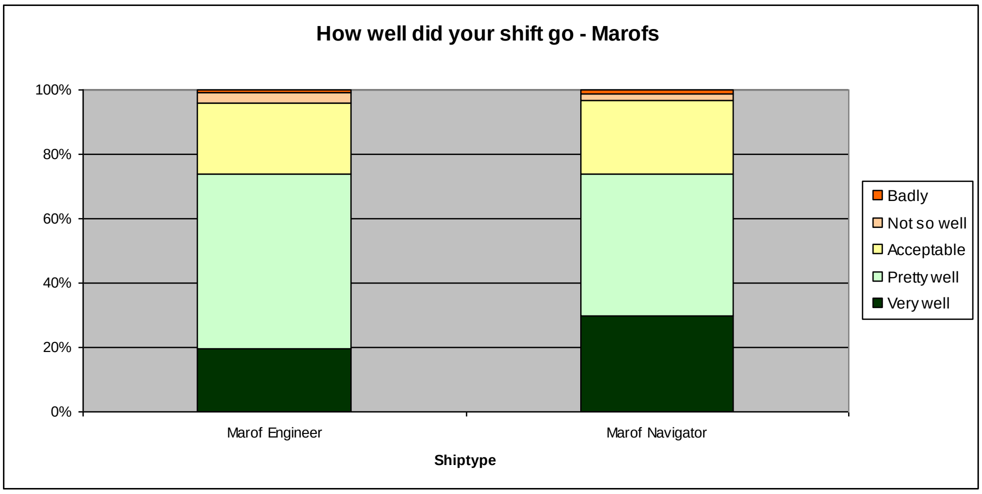


Figure 4-48 Judgments by the Marof as Engineer (left) and as Mate (right) on how well their shifts went.

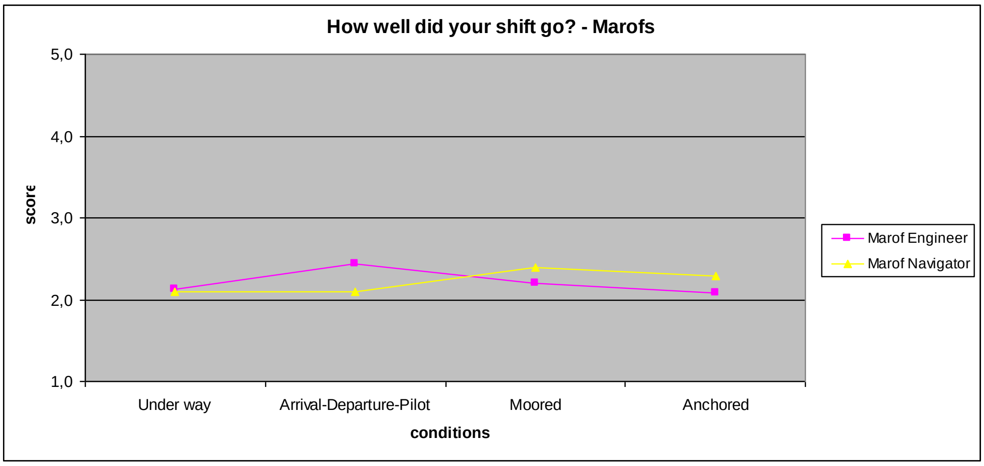


Figure 4-49 Judgment by the Marofs of how well the shift went, for the four voyage phases. 1: very well; 2: pretty well; 3: acceptable; 4: not so well; 5: badly.

In interviews with Marof ships, we noticed more often the existence of a team atmosphere, or even a family atmosphere. On these ships, personnel also tend to stay longer.

4.3.5 Voyages

On the Masters’ PDA there was an option to start a questionnaire about a completed voyage. This questionnaire was filled out 311 times (TS Masters: 177; MS Masters: 134). The questionnaires were not filled out every voyage. Some masters fill out more regularly than others.

For both types of ships, most of the voyages went well, but Masters of the MS ships more frequently qualified their voyages as “Very well”, compared to Masters of TS ships (mixed effects ANOVA $F(1,309)=33,53$; $p < .001$). Less than acceptable was chosen by both Masters in 3% of their voyages.

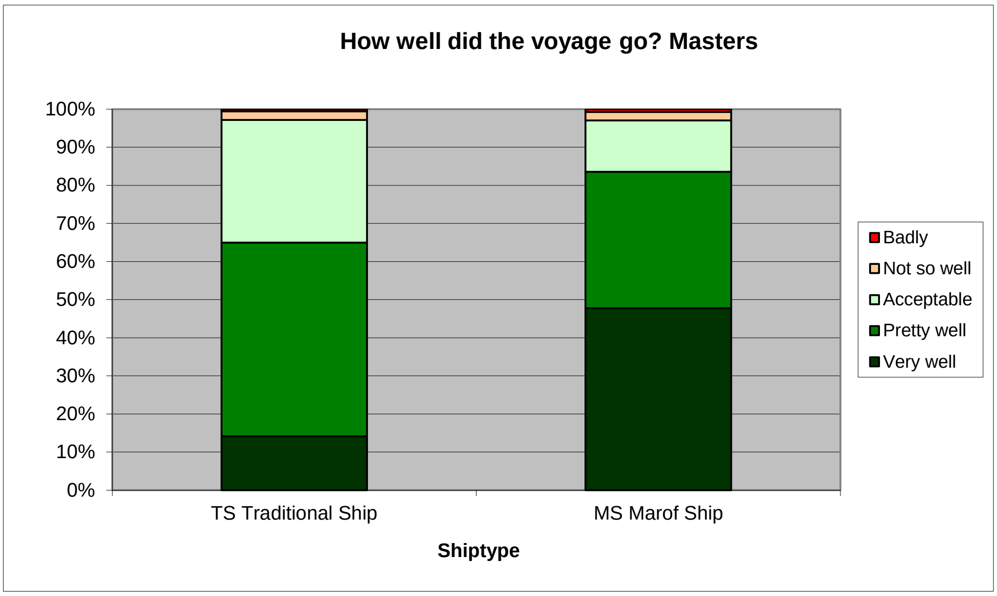


Figure 4-50 Assessments by the masters of how well their voyages went, for the different types of ships.

The Masters were also asked to judge the safety of their voyages (see Figure 4-51). “Very safe” is more often used by MS masters, whereas TS masters, in comparison with MS masters, more often choose for “Pretty safe. The TS Master judged 3 voyages (2%) as “a little unsafe” and 3 (2%) as “unsafe”; the MS Master judged 3 voyages (2%) as “a little unsafe” and 1 (1%) as “unsafe”. There was no statistically significant difference found between both types of ships in how the Masters judged the safety of their voyages (tested with a non-parametric test, Mann-Whitney. U=129, n.s.). In addition, the Masters were asked whether there were any “calamities” during their voyages. TS Masters reported 8 calamities (4.7%); MS Masters 5 (4.1%). No statistically significant difference was found ($\chi^2(1)=.81$, n.s.).

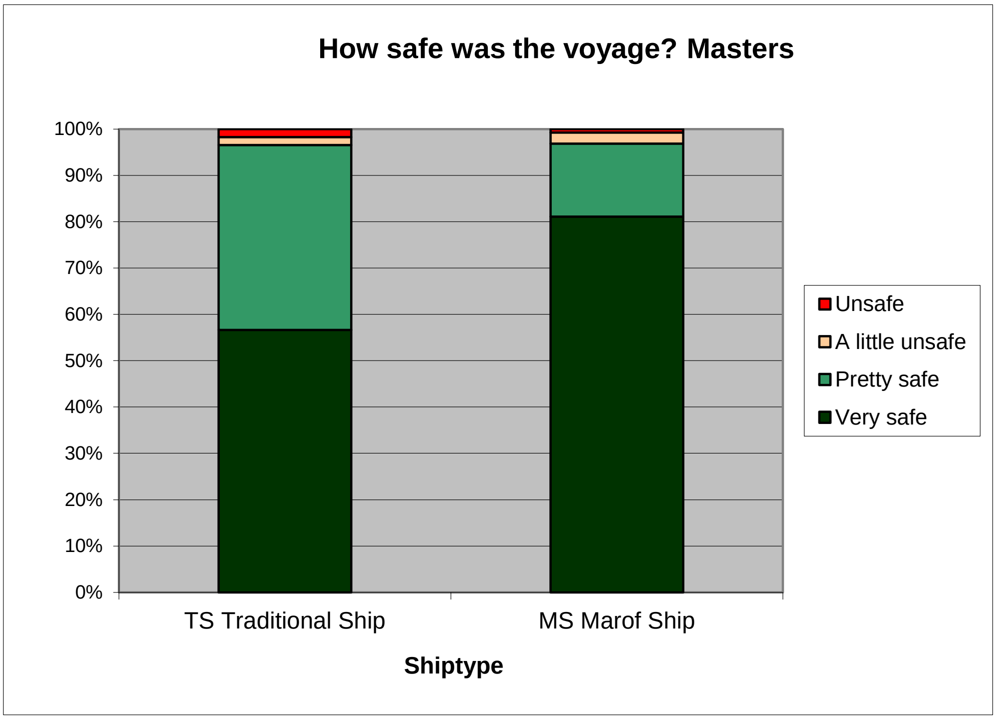


Figure 4-51 Assessments by the masters of how safe their voyages went, for the different types of ships.

5 Discussion

5.1 Safe Sailing

5.1.1 Incidents

A prominent outcome of this study is the insight in the number of incidents and critical situations during this longitudinal study, and the possible differences between the Traditional and the Marof crews.

- No *serious shipping incidents* were reported during this study of 311 voyages, and 57,692 measured hours, representing more than 6.5 years of continuous shipping.
- *Critical situations* have been reported 337 times, which is, on average, about once every voyage. No statistically significant difference was found between Marof crews and Traditional crews.
- Reported critical situations were 43 times classified as *technical failure*, which is about once every seven voyages. No statistically significant difference was found between Marof crews and Traditional crews.
- Reported critical situations were 136 times classified as *navigational* (collision or grounding danger*)*, which is about once every two voyages. No statistically significant difference was found between Marof crews and Traditional crews.

5.1.2 Subjective safety assessment

The types of crews didn't differ significantly in how the Masters judged the safety of their voyages. The Masters of Marof crews used more often “Very safe”, whereas Master of Traditional crews choose for “Pretty safe”. Of all 311 voyages, the safety of 10 voyages (3%) was judged as less than acceptable (six voyages at Traditional and four at Marof ships).

5.1.3 Fatigue

An important indication for (un)safe sailing is fatigue. This section discusses whether fatigue has been found and whether a difference is found between the two types of ships. Note that in this longitudinal field study, we didn’t measure fatigue directly, for instance by performance measurements tools or EEG, since it would have been impractical, if not impossible. Instead, we asked, at the start of the shift about how much the navigator had slept, and every hour during the shift, how busy and how tired the navigator was.

- For the Master, the Chief Mate as well as the Marof as Mate, a statistically significant difference was found between the crew types in *the amount of long sleep periods*, as reported at the start of every shift: Marof ship crews sleep considerably more often over 6 hours, which may contributes to limit fatigue.
- For the Master, a statistically significant difference was found between the crew types in *tiredness*, as reported during their shifts. Marof ship crews consequently report about 20% lower tiredness, compared to the Traditional ship crews, while both crew types report comparable work load. Note that the level of tiredness was for both types of crews never more than “a little tired”, on average, which doesn’t indicate the existence of fatigue for both types of crews.
- As a general question, after each shift, the members of the crews were asked how well their watch went. Marof crews judged their shifts statistically significant more often as “pretty well” to “very well” than Traditional crews do.

Overall, we can conclude that Marof crews sail at least as safe as Traditional crews. When serious shipping incidents occur, they are more frequently due to navigational failure and extreme weather than technical failure.

5.2 Technical functioning

5.2.1 Engineering on board

- Chief Engineers have more time available for maintenance than the Marofs. Chief Engineers have a regular sleeping rhythm, during all voyage phases, while the Marof does not. Chief Engineers sleep much more often over six hours, compared to Marofs.
- At the start of their shifts, Chief Engineers report to be more tired than the Marofs.
- After their shifts, Chief Engineers report to be 20% more tired than Marofs, while they report comparable work load.
- The average number of alarms is comparable for both types of ships.
- In 16227 shifts, there were 43 critical situations reported that were classified as technical failure. No statistically significant difference was found between Marof ships and Traditional ships.
- The Marofs judged the Engineering shift much more often as “pretty well” to “very well” than the Chief Engineers.

Compared to Marofs, Chief Engineers sleep better, but report to be more tired before and after their shift. They have more time available for maintenance, but no indications have been found that Marof ships function less well technically than Traditional ships.

5.2.2 Shore Support

In contrast to what was expected, not only the Marof ships but also the Traditional ships frequently made use of Shore Support.

- MS Masters reported the need for Shore Support statistically significant more often than TS Masters (28% of their *voyages* versus 15%). If they did, they were about equally satisfied, compared to the TS Masters.
- Marofs as Engineer needed Shore Support statistically significant more often than Chief Engineers (7% of their *shifts* versus 4%). If needed, the Marofs were more often satisfied with it, compared to the Chief Engineers.
- The shore support organisation personnel we have interviewed indicated that an important number of failures of modern engines cannot be repaired by either a Chief Engineer or a Marof as Engineer.

5.3 Work Satisfaction and Atmosphere

The results clearly indicate that on Marof ships, the shifts went more satisfactory and the crew was less tired than on Traditional ships.

- Navigation shifts went statistically significant more satisfactory on Marof ships than on Traditional ships.
- Engineering shifts went statistically significant more satisfactory on Marof ship than on Traditional ships.
- Masters and Chief Mates sleep statistically significant more often over six hours on Marof ships than on Traditional ships.
- Officers on Marof ships are less tired compared to Officers on Traditional ships.
- From interviews with the crews we noticed more often team spirit on Marof ships, while on Traditional ships we noticed more often resentment about the

fact that the work load was not equally distributed, especially during periods of heavy work load.

5.4 Recommendations

– Since the new manning concept has a positive effect on how tired and how satisfied the crew is, we recommend implementing this concept on as many shortsea ships as possible.
– This study has shown that engineering work aboard modern shortsea ships can be done in combination with navigational work. Also for traditional crews, one may consider organizing proper additional work for the Chief Engineer, aimed at relieving the navigation team and creating a better team atmosphere.
– The measurements collected in this study contain valuable data that could not be further analysed within the available resources for this study.
  Additional funding will lead to further insight, for example in the determining factors for a “happy ship”.
– This study has demonstrated that a decent field study in the context of shortsea shipping can well assess the safety and feasibility of new crew concepts.
  New shipping areas can be investigated equally well.

6 Signature

Soesterberg, March 2011

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Head of department

TNO Soesterberg

Dr. W.M. Post
Author

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B Participating ships

Ship Name	**Shipping Company**
MS Adamas	Wagenborg
MS Alana Evita	Wagenborg
MS Albertus F	Wagenborg
MV Ashley	Wagenborg
MV Christina	Wagenborg
MV Derk	Wagenborg
MS Eems Dollard	Amasus
MS Eems Sprinter	Amasus
MV Flinterbaltica	Flinter
MV Flinterbelt	Flinter
MV Flinterbirka	Flinter
MV Flinterbothnia	Flinter
MV Flinterbright	Flinter
MV Kelt	Wagenborg
MV Lelie	Wagenborg
MV Marinda	Wagenborg
MS Novatrans	Amasus
MV Panda	Wagenborg
MV Panta Rhei	Wagenborg
MS Rhodanus	Amasus
MS Rimini	Amasus

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