Southampton SOLENT University

A Final Report to the UK Maritime and Coastguard Agency:

"Modelling the Hours of Work and Rest of Merchant Navy Watch Keepers and Tug Crews"

Warsash Maritime Academy

WMA-SSU/SRI_MARCH 2017

Contents

EXECUTIVE SUMMARY

The aim of this project was to answer the following question:

What are the effects of working various hours of work and rest patterns, commonly found in use by Merchant Navy watch keepers?

A separate study also investigated the working patterns of selected tug crews.

The method used the MARTHA fatigue prediction software tool. For the study of watch keeper patterns, an uninformed model was used in which different watch permutations were compared and analysed. The analysis was able to provide the risk of falling asleep under different watch patterns. Two variations to the basic watch patterns were also analysed: the introduction of disruptions to off watch periods and the effect of changing the start time of different watch regimes.

The MARTHA software was also used to input records of work hours from a number of different crew members serving on tugs and to analyse the data to provide the risk of falling asleep for different circadian types.

For the watch keeping pattern study, the following research questions were posed:

1. Which 2-watch system is the most problematic?
2. Which 3-watch system is the most problematic?
3. To what extent is each and every watch system vulnerable to frequently occurring sleep disruptions?
4. What is the effect of varying of watch start times in 6/6 and 12/12?

Taking into account both evening and morning circadian types, the most effective 2-watch systems is the Royal Navy "dog-watch" system, with the highest risk of falling asleep being the 12/12 system. The 4/8 3-watch system was shown to be at relatively low risk compared to other systems. The study also concluded that the amount of monthly sleep is reduced by introducing overtime work in virtually all watch systems and teams.

For the study of tug data, hours of work data were collected from a number of different crew of various ranks working aboard different tugs of the same company. A total of 23 sets of data were obtained. After analysis, the study concluded that individuals who are morning types, and who are deprived of the opportunity, or are unable to nap, are likely to get the least amount of daily sleep and are at the most risk of falling asleep on a daily basis. When the risk is expressed as a percentage of the total time worked, the least risk is experienced by morning types who are able to nap. Conversely, the highest risk experienced over the total time worked is for morning types who are not afforded the opportunity to nap.

Furthermore, their risk of falling asleep is the highest of all categories and hypothetically, for more than 10% of their working time, they are at risk of experiencing micro sleeps associated with such risk levels.

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 Aim and objectives

This report is from a consortium led by Southampton Solent University (SSU). It is in response to an invitation from the UK Maritime and Coastguard Agency (MCA), to conduct a study to investigate the hours of work and rest of Merchant Navy watch keepers and tug crews. This section of the report addresses the aims and objectives of the study.

The UK Maritime and Coastguard Agency (MCA) wished to investigate the hours of work and rest of Merchant Navy watch keepers and tug crews, particularly in relation to:

1 the effect on seafarer fatigue of various watch keeping and work patterns;

2 the impact of various work patterns on different circadian types;

3 the likely impact on maritime safety;

4 comparisons with other watch keeping systems;

5 general suitability as “acceptable” systems of hours of work and rest given their working conditions.

The aim of this project was to examine:

the effects of working various hours of work and rest patterns, commonly found in use by Merchant Navy watch keepers and tug crews.

The objectives of the study were:

i. an investigation into the various watch keeping and work patterns of different maritime sectors (as described in detail in following sections), using the theoretical MARTHA model for the prediction of the risk of falling asleep;

ii. from the results of the investigation, an assessment of these patterns on sleepiness and maritime safety;

iii. the provision of a report, supported by presentation material and publications.

2. METHODOLOGY

2.1 The Scope of the Study

The following scope of work was agreed:

2.1.2 Merchant Navy Watchkeeping Patterns

2.1.2.1 Investigate, using MARTHA software, the following 2-watch systems:

i. 6/6
ii. 8/8
iii. 12/12
iv. 7/5/5/7 with 2 variants
v. A Royal Navy ”dog” watch system

2.1.2.2 The three 3-watch keeping systems investigated were:

vi. 4/8 3-watch system
vii. 5/5/4/5/5 – the “so-called” five and dime system
viii. US submarine system: 6/6/6 starting 30 minutes earlier (eg 1130)

2.1.2.3 The following general variables were taken into account where appropriate:

- routine and overtime work carried out in addition to watchkeeping;
- the effect of variation in start/finish times of selected watch keeping system;
- the effect of recovery in off watch periods;

2.1.2.4 The assessments included:

- watch keeping officers;
- Masters (as part of, and not part of regular watch keeping systems);
- typical circadian types of seafarers e.g. evening and morning types;
- the use of other available data as appropriate.

2.1.3 Tug crew working hours

Investigate, using MARTHA software, the working patterns of tug crews. The data were obtained from the hours of work and rest forms provided by Masters, Mates, Chief Engineers, watch keepers and deckhands on a variety of different tugs working in UK ports.

2.2 Methodology and work plan.

2.2.1 Introduction

The methodology included the following elements:

- A theoretical study which compared different watch permutations using the MARTHA fatigue prediction software tool;
- Analysis of the MARTHA data and the production of a report.

2.2.2 Theoretical Study using MARTHA software

The theoretical study used the software called MARTHA, which is based on the widely validated three process model of alertness regulation.[1] These processes are (1) a homeostatic process "S curve" which describes the gradual reduction in alertness with time awake; (2) an exponential recovery process from S taking place during sleep, and (3) a circadian process describing the endogenous variation in alertness as a function of the time of day. Comparisons have been made in two different ways, using both watch keeping patterns and actual recorded hours of work to predict sleep and sleepiness in the different watch systems and the tug crews respectively.

2.3.1 MARTHA model comparisons

For the watch keeping patterns study, MARTHA has used only the theoretical working hours (i.e. the watch regime) as an input. Based on this, sleep and sleepiness have been predicted for a sufficient period to give a reliable result. Such a comparison answers the question as to which of the watch systems has the best sleep opportunities as well as which of the systems is associated with the highest levels of sleepiness and thus will theoretically include the highest safety risk.

For the tug crew comparisons, MARTHA uses the individuals own hours of work records, thereby producing an evaluation of alertness and sleepiness. This is expressed as a percentage risk of falling asleep. This has been calculated for two different circadian types – evening and morning types.

[1] Akerstedt, T., and Folkard, S. (1997). The three-process model of alertness and its extension to performance, sleep latency, and sleep length. Chronobiology International, 14, 115-123.

3 ANALYSIS and DISCUSSION OF RESULTS

This section covers the data analysis of the results from both the study of MN Watch keepers as well as the study of tug crews hours of work and rest.

3.1 MN Watch Keeping Systems

Ten different watch systems have been subject to the current investigation. These are divided into two groups; the *2-watch systems* where two watch teams/keepers are alternating versus *3-watch systems* where three watch teams/keepers are rotating. Assuming work to be continuing 24/7, this implies a significant difference in average daily working hours between 2-watch systems (12 h/day) and 3-watch systems (8 h/day). Hence, it is by no means surprising that those working in a 3-watch system are better off in terms of sleep and fatigue than those working in a 2-watch system. Comparisons should therefore always be made within these two groups and not across groups. Furthermore, one can distinguish between *dog watch* systems where watches for the individual watch team/keeper are rotating (e.g. 8/8/8) and systems in which one is working the same watch(es) every day (e.g. 6/6). The latter systems would need separate analyses for each team.

The following research questions will be covered in separate sections of this report:

1. Which 2-watch system is the most problematic?
2. Which 3-watch system is the most problematic?
3. To what extent is each and every watch system vulnerable to frequently occurring sleep disruptions?
4. What is the effect of varying of watch start times in 6/6 and 12/12?

3.1.1 Which 2-watch system is the most problematic?

The following 2-watch systems were under investigation:

- 6on6off (0000-0600; 0600-1200; 1200-1800; 1800-0000)
- 12on12off (0000-1200; 1200-0000)
- 8on8off (0400-1200; 1200-2000; 2000-0400)
- 7/5/5/7 v1 (0000-0500; 0500-1200; 1200-1900; 1900-0000)
- 7/5/5/7 v2 (0100-0800; 0800-1300; 1300-1800; 1800-0100)
- 7/5/5/7 v3 (0000-0700; 0700-1200; 1200-1700; 1700-0000)
- Royal Navy (0000-0400; 0400-0800; 0800-1200; 1200-1600; 1600-1800; 1800-2000; 2000-0000)

In terms of the amount of sleep per 24-hour period that is predicted to take place, the watch systems are compared in Table 1. The term "major sleep" refers to the main predicted sleep, whilst "other" sleeps refer to shorter sleeps which do not necessarily occur on a daily basis. Less than 5 hours of sleep is considered clearly insufficient and therefore these sleep durations are indicated in red. Note that, although the average daily sleep is highest in 12on12off, a substantial difference is observed between the two different 12on12off watch teams.

Table 1: Sleep predictions for all 2-watch systems.

System	Team	Type[1]	Major sleep	Other sleep	Total sleep length
6on6off	00-06/12-18	M	0640-1034	2142-2330	**5:42**
		E	0639-1130	2306-2330	**5:15**
6on6off	06-12/18-00	M	0039-0530	n/a	**4:51**
		E	0039-0530	1242-1425[2]	**5:17**
12on12off	00-12	M	1241-1516	2106-2330	**4:59**
		E	1240-1627	2249-2330	**4:28**
	12-00	M	0040-0719	n/a	**6:40**
		E	0040-0805	n/a	**7:25**
8on8off		M	0439-1028[3]	2148-0330[3]	**5:46**
		E	0438-1130[3]	2336-0330[3]	**5:23**
7/5/5/7 v1	00-05/12-19	M	0539-0953	2154-2330	**5:50**
		E	0538-1119	n/a	**5:41**
	05-12/19-00	M	0039-0430	1242-1442[3]	**4:51**
		E	0040-0430	1241-1423	**5:32**
7/5/5/7 v2	01-08/13-18	M	2136-0030	0841-1127	**5:40**
		E	0839-1230	2306-0030	**5:15**
	08-13/18-01	M	0139-0730	n/a	**5:51**
		E	0139-0730	n/a	**5:51**
7/5/5/7 v3	00-07/12-17	M	0740-1117	2136-2330	**5:31**
		E	0739-1130	2225-2330	**4:56**
	07-12/17-00	M	0039-0630	n/a	**5:51**
		E	0040-0630	n/a	**5:50**
Royal Navy "dog-watch"		M	0038-0330[3]	0439-0730[3] 0840-1130[3] 2118-2330[3]	**5:23**
		E	0438-0730[3]	0040-0330[3] 0840-1130[3] 1242-1432[3] 2306-2330[3]	**5:23**

[1] *M = morning, E = evening*
[2] *Sleep is predicted to take place once every 4 days*
[3] *A sleep is predicted to take place every 2 days*

Overall average daily sleep durations can be calculated for every watch system. These are shown in Figure 1.

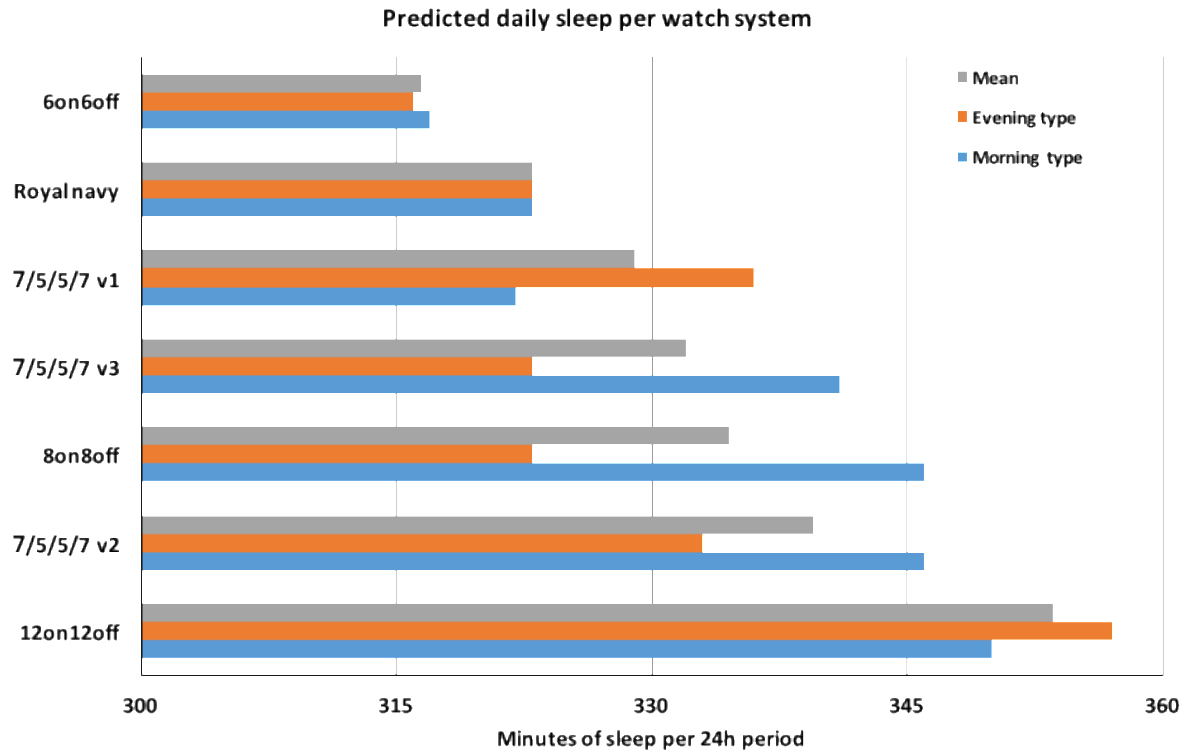


Figure 1. Predicted average total sleep per 24h period for each 2-watch system.

From a sleep perspective, it is clear that the 6on6off watch system is associated with the least amount of sleep, both for morning types and evening types. However, even if the average total sleep is equally divided between the two watch teams, it does not necessarily imply that on-watch sleepiness is highest too. From a safety perspective, the percentage of time on watch at a high sleepiness level is of utmost relevance. KSS values 7 or higher are associated with the occurrence of micro sleeps. The percentage of time spent at KSS 7 or higher can therefore be expressed as the percentage of time at risk.

Table 2 describes the percentage of time at risk for morning and evening types in each and every 2-watch system.

Table 2. Percentage of time at risk for morning (M) and evening (E) types for all the different 2-watch teams

System	Team	Type[1]	Time at risk (KSS ≥ 7)
6on6off	00-06/12-18	M	22%
		E	34%
	06-12/18-00	M	10%
		E	0%
12on12off	00-12	M	24%
		E	84%
	12-00	M	0%
		E	0%
8on8off		M	19%
		E	15%
7/5/5/7 v1	00-05/12-19	M	18%
		E	24%
	05-12/19-00	M	8%
		E	0%
7/5/5/7 v2	01-08/13-18	M	0%
		E	41%
	08-13/18-01	M	7%
		E	0%
7/5/5/7 v3	00-07/12-17	M	23%
		E	42%
	07-12/17-00	M	1%
		E	0%
Royal Navy		M	8%
		E	8%

[1] *M = morning, E = evening*

Rather than showing the time at risk for every individual in each and every watch system, it is worthwhile drawing the picture of the time that ship operations as a whole are at risk, that is, taking all on board into account (Figure 2).

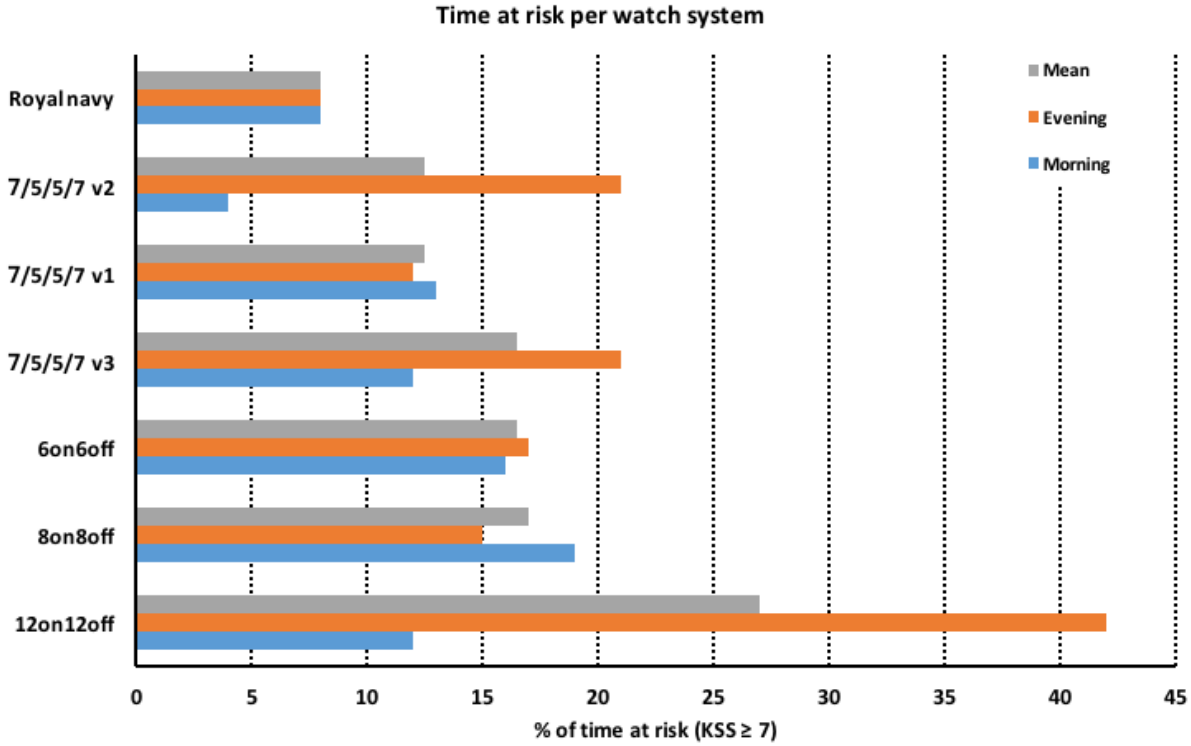


Figure 2. Percentage of time a ship would be at risk under each 2-watch system.

In interpreting MARTHA results, it is important to understand the difference between time at risk (as measured in hours and minutes, or just minutes) as opposed to the proportion of time at risk, expressed as a percentage of total time.

The "N-1" Chi-squared test method was used for comparing daily minutes at risk. The detailed results are shown in tables in Appendix 5 where, for clarity, only significance levels are displayed.

In summary, for morning types, the 7/5/5/7 v2 system is significantly better than all other 2-watch systems in terms of time at risk. 6on6off and 8on8off do not differ and are the worst 2-watch systems for just morning types (Appendix Table 5a).

For evening types, the Royal Navy system is significantly better than all other 2-watch systems. At the other end of the spectrum, the 12on12off system is significantly worse than all the other 2-watch systems (Appendix Table 5b).

Clearly, quite substantial differences exist between morning types and evening types. Therefore, taking the average of morning and evening types would form the ultimate test of which 2-watch system is best. (Appendix Table 5c)

In conclusion, the 2-watch systems can be ordered as follows with their respective risk percentages, the watch system with the least risk ranked 1 and the watch system with the highest risk ranked 7:

1.	Royal Navy system	8%
2.	7/5/5/7 v1	12.5%
	7/5/5/7 v2	12.5%
4.	6on6off	16.5%
	7/5/5/7 v3	16.5%
	8on8off	17%
7.	12on12off	27%

Although the Royal Navy System comes first in terms of time at risk, it has the major complication of having the shortest watches and therefore also the shortest time off between watches. As a consequence, sleep is very fragmented, having possible side effects that would make the system far from optimal.

Fragmented sleep indicates a poor quality of sleep which may have an impact on safe operations, as well as its effects on individual behaviour and team cohesion.

3.1.2 Which 3-watch system is the most problematic?

The following 3-watch systems were under investigation:

- 4on8off (0000-0400; 0400-0800; 0800-1200; 1200-1600; 1600-2000; 2000-0000)
- Five and dime (2200-0200; 0200-0700; 0700-1200; 1200-1700; 1700-2200)
- US submarine (2330-0530; 0530-1130; 1130-1730; 1730-2330)

In terms of the amount of sleep per 24-hour period that is predicted to take place, the 3-watch systems compare as shown in Table 3.

Table 3. Sleep predictions for all 3-watch systems.

System	Team	Type[1]	Major sleep	Other sleep	Total sleep length
4on8off	00-04/12-16	M	0439-0909	2200-2330	**06:00**
		E	0438-1033	n/a	**05:55**
4on8off	04-08/16-20	M	2112-0330	n/a	**06:18**
		E	2342-0330	0841-1108	**06:15**
4on8off	08-12/20-00	M	0039-0720	n/a	**06:41**
		E	0041-0730	n/a	**06:49**
Five and dime		M	2241-0626[2]	0239-0833[2] 2206-0130[2] 0741-1006[2]	**06:30**
		E	2336-0630[2]	0239-0928[2] 0740-1137[2] 2354-0130[2]	**06:25**
US submarine		M	0010-0718[2]	2212-0500[2] 0610-1031[2] 2154-2300[2]	**06:28**
		E	0011-0805[2]	0609-1203[2] 0000-0500[2] 2254-2300[2]	**06:18**

[1] *M=morning, E=evening*
[2] *A sleep is predicted to take place every three days*

Overall average daily sleep durations can be calculated for every watch system. These are shown in Figure 3. Note that, although the average daily sleep is highest in the "five and dime" system, all sleep durations are very close to each other.

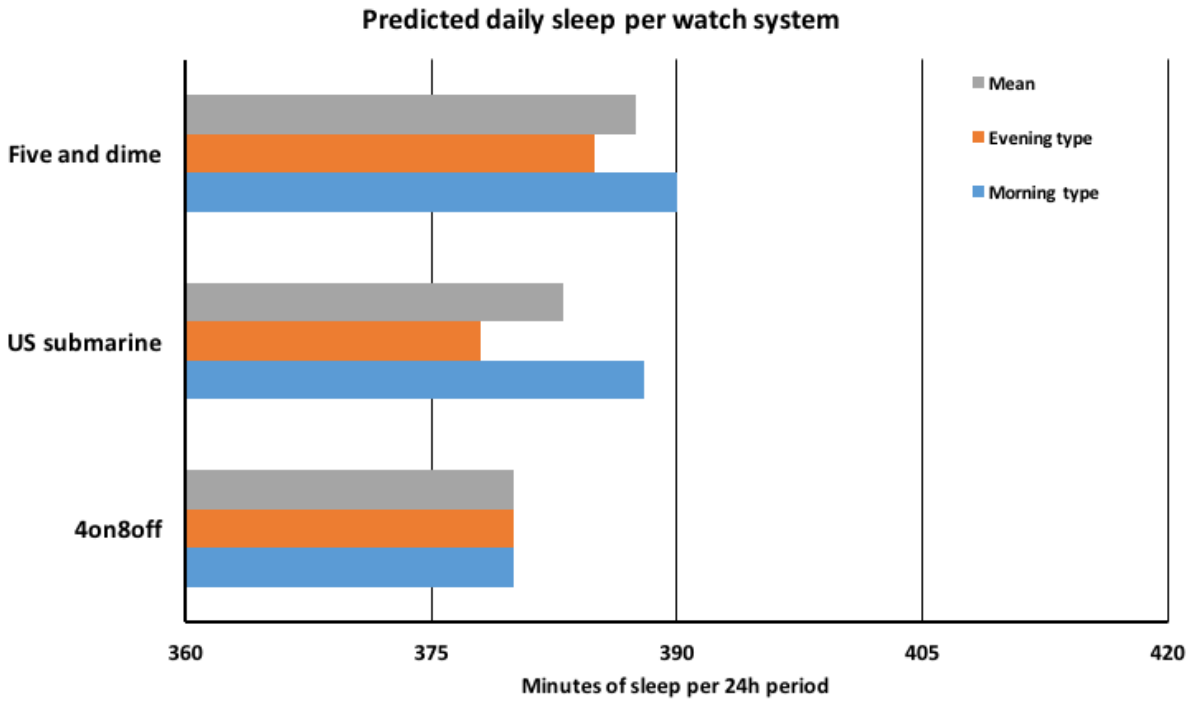


Figure 3. Predicted average total sleep per 24h period for each 3-watch system.

Table 4. Percentage of time at risk for morning (M) and evening (E) types for all the different 3-watch teams

System	Team	Type[1]	Time at risk (KSS ≥ 7)
4on8off	00-04/12-16	M	14%
		E	22%
4on8off	04-08/16-20	M	0%
		E	0%
4on8off	08-12/20-00	M	0%
		E	0%
Five and dime		M	6%
		E	0%
US submarine		M	16%
		E	17%

[1] *M=morning, E=evening*

Rather than showing the time at risk for every individual in each and every watch system, it is worthwhile drawing the picture of the time the ship operations as a whole are at risk, that is, taking all on board into account (Figure 4).

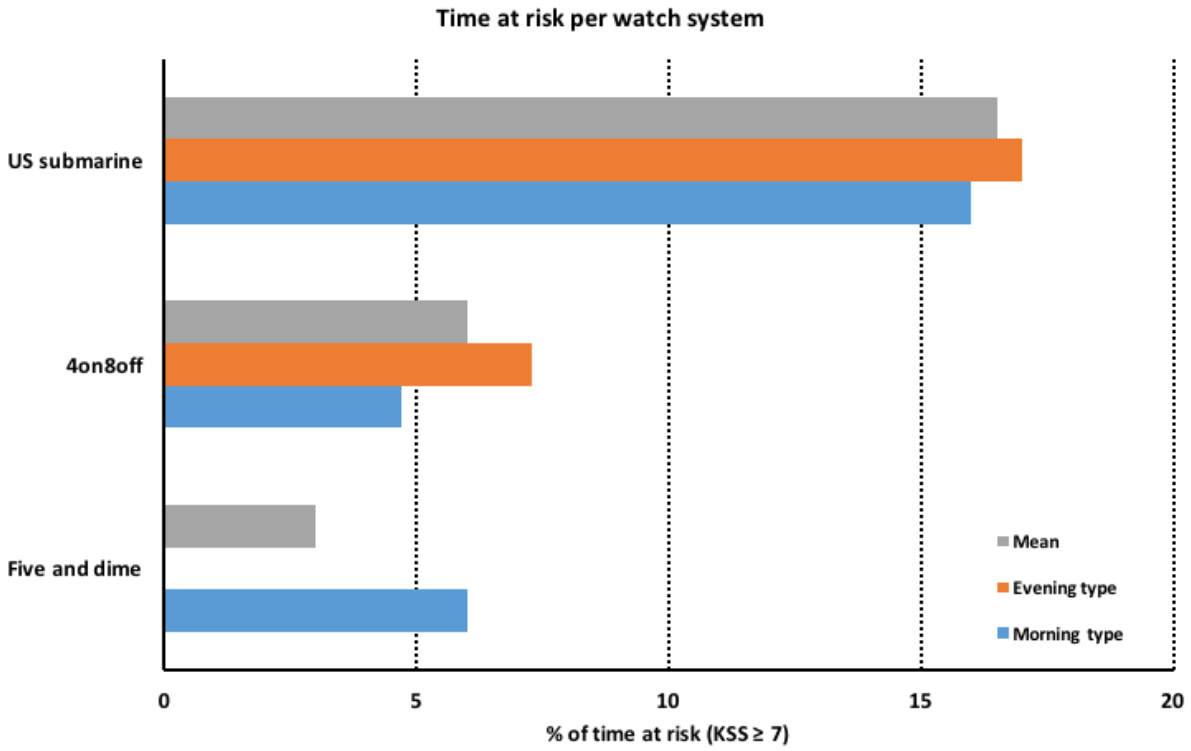


Figure 4. Percentage of time a ship would be at risk under each 3-watch system. (Note: In the "five and "dime" system, there is zero risk for the evening type)

As before, the "N-1" Chi-squared test method was used for comparing daily minutes at risk. Table 5d, showing the significance levels for this comparison, is in Appendix 5.

In summary, the 3-watch systems can be ranked as follows, based on their respective risk percentages, with the watch system with the lowest risk ranked 1 and the watch system with the highest risk ranked 3:

1. Five and dime 3%
2. 4on8off 6%
3. US submarine 16.5%

This result suggests that ships operating the "five and dime" or 4on8off systems are at a lower risk than a ship running any 2-watch system. The difference between system 1 and 2 is statistically significant, and the difference between these two systems and system 3 is highly significant.

3.1.3 To what extent is each and every watch system vulnerable to frequently occurring sleep disruptions?

Sleep disruption to off watch periods can, of course, occur at any time at sea or in port and last for varying periods. Consequently, for the purpose of this study, it was necessary to establish a "standard disruption". In this study, the vulnerability to frequently occurring sleep disruptions is tested by adding 3 hours of work in direct connection to a watch at a clock time that would arguably be most disruptive and at intervals of about 3 days. This period and frequency were arrived at by taking typical coastal voyages with port visits every three days as a basis and assuming that in-port work would affect off-watch periods by approximately three hours in a port period.

For each modelled working month, therefore, nine such additions are included, adding up to an extra working time of 27 monthly hours. The timing of these 3 hours is described in Table 5.

Table 5. Timings of the 3 hours of modelled overtime work

System	Team	Timing of overtime work
6on6off	00-06/12-18	06:00 – 09:00
	06-12/18-00	00:00 – 03:00
12on12off	00-12	21:00 – 00:00
	12-00	00:00 – 03:00
8on8off		04:00 – 07:00
7/5/5/7 v1	00-05/12-19	05:00 – 08:00
	05-12/19-00	00:00 – 03:00
7/5/5/7 v2	01-08/13-18	22:00 – 01:00
	08-13/18-01	01:00 – 04:00
7/5/5/7 v3	00-07/12-17	21:00 – 00:00
	07-12/17-00	00:00 – 03:00
Royal Navy		04:00 – 07:00
4on8off	00-04/12-16	04:00 – 07:00
	04-08/16-20	01:00 – 04:00
	08-12/20-00	00:00 – 03:00
Five and dime		02:00 – 05:00
US submarine		23:30 – 02:30

Figure 5 illustrates how adding these 3 hours of extra work approximately every third day would affect the percentage of time at risk. Note that by introducing extra working hours, the percentage at risk will be calculated over a greater number of working hours. This means that a small decrease in % of time at risk will still mean an increase in absolute time (i.e., minutes) at risk.

This is illustrated by the evening types working in team 00-12 under a 12on12off regime. In their case, the extra work will lead to a 4% reduction in working time at risk. However, in absolute terms, minutes at risk are increased by 354 minutes. Interestingly yet not unexpectedly, it can be observed that what previously looked like the ideal 2-watch system, the Royal Navy system, now has shown its shortcoming: it is among the systems that are most sensitive to modest amounts of overtime work.

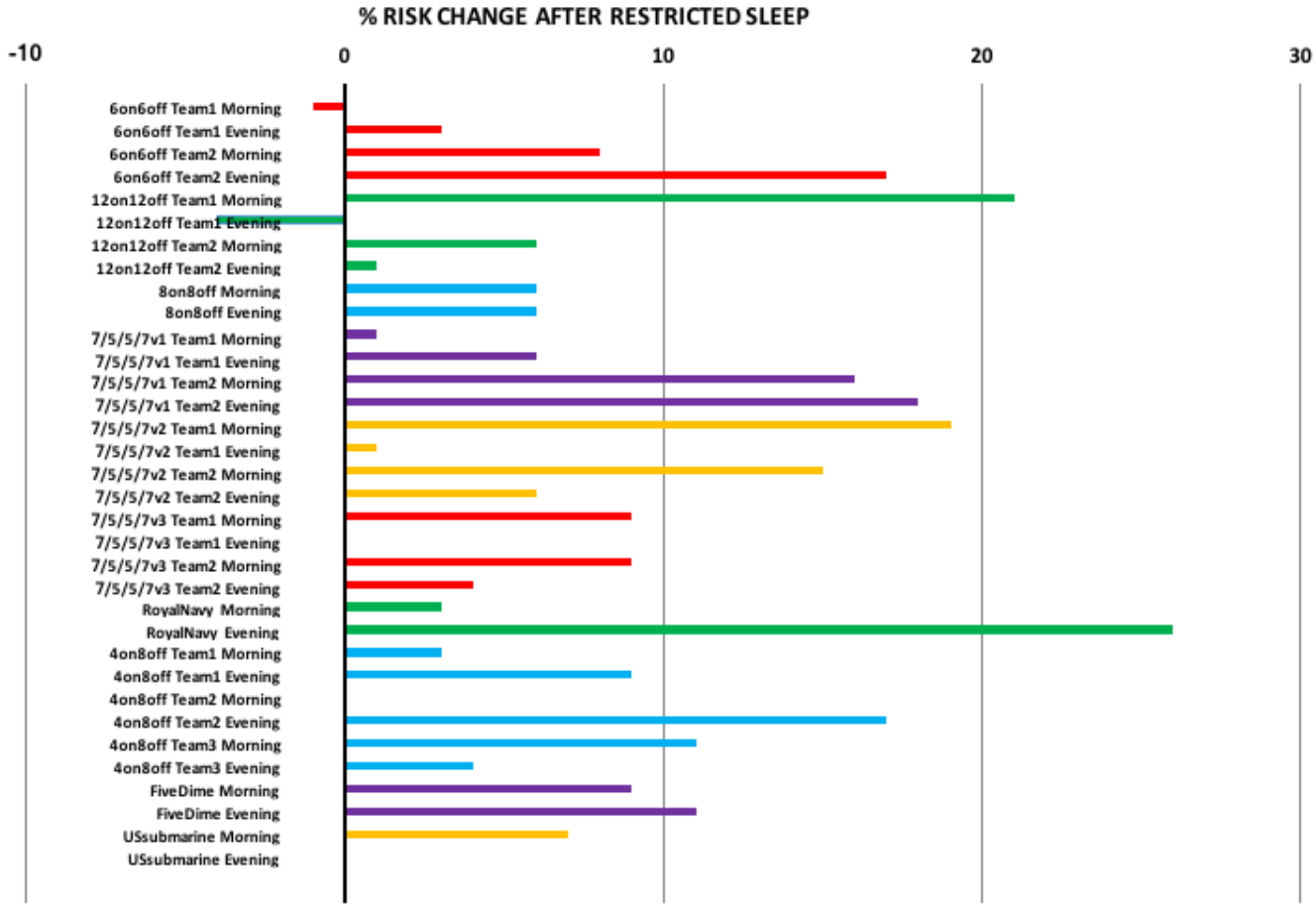


Figure 5. Change in percentage of time at risk in every watch system by introducing 3 hours of extra work every third day.

Table 6. Original total sleep and the change in monthly sleep duration as a consequence of 9x3 hours of overtime work.

System	Team	Morning/evening person[2]	Total sleep (minutes/month)	Sleep change (minutes/month)
6on6off	00-06/12-18	M	10 770	-362
		E	10 047	-378
	06-12/18-00	M	9 322	56
		E	10 068	-475
12on12off	00-12	M	9 095	-493
		E	8 257	-147
	12-00	M	12 022	-514
		E	13 349	-654
8on8off		M	10 314	-497
		E	9 667	-549
7/5/5/7 v1	00-05/12-19	M	11 044	-309
		E	10 793	-569
	05-12/19-00	M	9 251	-227
		E	10 456	-569
7/5/5/7 v2	01-08/13-18	M	10 783	-584
		E	10 101	-370
	08-13/18-01	M	10 976	-1585
		E	11 034	-579
7/5/5/7 v3	00-07/12-17	M	10 504	-457
		E	9 427	-262
	07-12/17-00	M	11 000	-772
		E	11 051	-382
Royal Navy		M	10 183	-202
		E	10 286	-738
4on8off	00-04/12-16	M	11 342	-259
		E	11 205	-532
	04-08/16-20	M	11 724	-294
		E	11 550	-465
	08-12/20-00	M	12 420	-1334
		E	12 739	-1581
Five and dime		M	12 215	-321
		E	12 118	-411
US submarine		M	12 109	-487
		E	11 913	-643

[2] *M=morning, E=evening*

The amount of monthly sleep is reduced by introducing overtime work in virtually all watch systems and teams, as can be seen in Table 6 above.

3.1.4 What is the effect of varying watch start times in 6/6 and 12/12?

Watch handover times do look suboptimal in both 6on6off and 12on12off systems, where the toughest hours of the day for staying awake and alert (i.e. between midnight and 6:00) are entirely on the shoulders of the same watch team. Therefore, the effect of a variation in start times for these two watch systems was studied.

For the 6on6off system, start times in the tested variations have been shifted 3 hours forward. Hence, the 00:00 to 06:00 watch would now be a 03:00 to 09:00 watch and the 18:00 to 00:00 watch would become a 21:00 to 03:00 watch, etc.

In the case of the 12on12off system, times have been shifted 4 hours forward. Watches would then move from 00:00 to 12:00 to 04:00 to 16:00, and from 12:00 to 00:00 to 16:00 to 04:00.

For a thorough investigation, all 5 diurnal types were now taken into account. That is, extreme morning types, morning types, neutral types, evening types, and extreme evening types. Variables under investigation were the daily amount of sleep and the time at risk.

Table 7: Sleep opportunities under original and alternative watch handover timings.

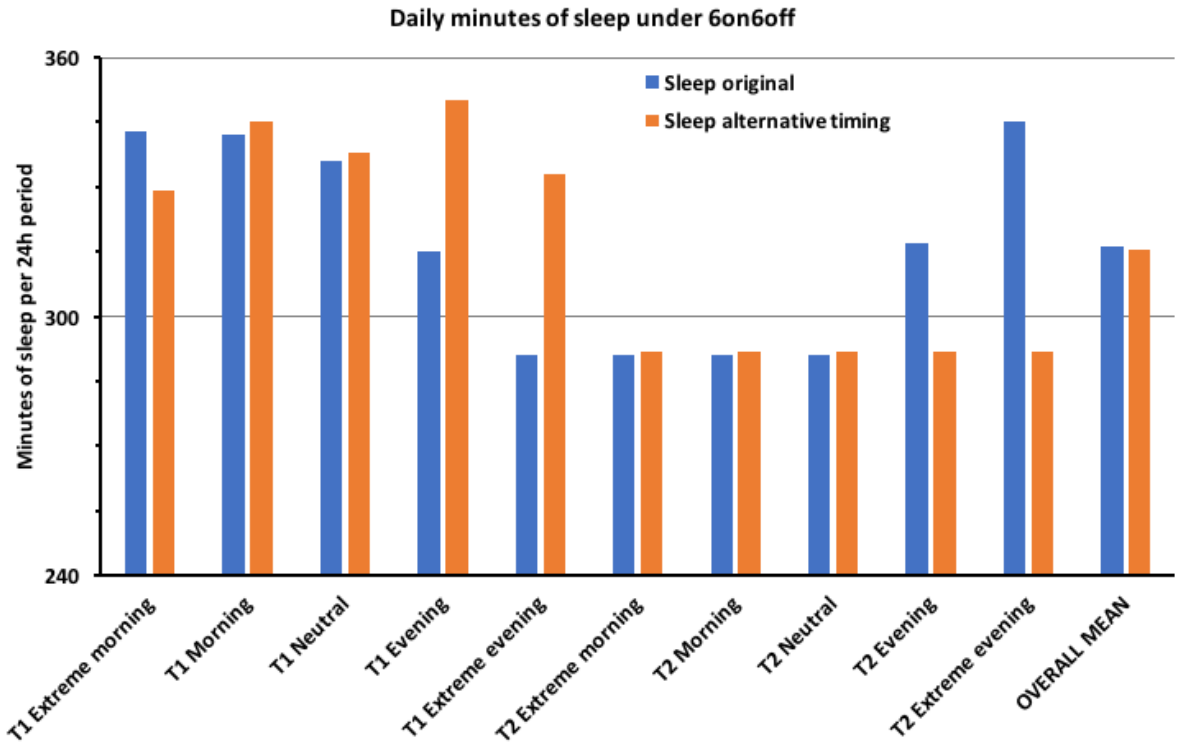
System	Team	Morning/evening person	Sleep under original condition	Sleep under variation
6on6off	00-06/12-18	Extreme morning	0639-1021 & 2129-2330	2140-0230 & 0947-1145[3]
		Morning	0640-1034 & 2142-2330	2141-0230 & 0947-1138[4]
		Neutral	0639-1103 & 2218-2330	2145-0230[4] & 2210-0230[4] & 0946-1156[4]
		Evening	0639-1130 & 2306-2330	2329-0230 & 0946 -1235
		Extreme evening	0639-1130	0944-1417 & 0129-0230
	06-12/18-00	Extreme morning	0039-0530	0338-0830
		Morning	0039-0530	0338-0830
		Neutral	0039-0530	0338-0830
		Evening	0039-0530 & 1242-1425[1]	0338-0830
		Extreme evening	0122-0530[2] & 0045-0530[3] & 1245-1503[3] & 1246-1443[3]	0338-0830
12on12off	00-12	Extreme morning	2054-2330 & 1241-1506	2106-0330
		Morning	1241-1515 & 2105-2330	2118-0330
		Neutral	1241-1537 & 2136-2330	2130-0330
		Evening	1239-1627 & 2248-2330	2200-0330
		Extreme evening	1243-1713	2200-0330
	12-00	Extreme morning	0039-0713	0439-1005
		Morning	0039-0720	0439-1008
		Neutral	0039-0733	0439-1016
		Evening	0041-0806	0439-1033
		Extreme evening	0200-0944	0440-1114

[1]sleep predicted to take place once every 4 days
[2]sleep predicted to take place twice every 3 days
[3]sleep predicted to take place once every 3 days
[4]sleep predicted to take place once every 2 days

The total amount of daily sleep under 6on6off is plotted in Figure 6, where T1 represents Team 1, either working 00:00 to 06:00 or 03:00 to 09:00, and T2 represents Team 2, either working 06:00 to 12:00 or 09:00 to 15:00. Some people get more sleep under the alternative timings (e.g. evening people in Team 1), whereas others will get less sleep under the alternative timings (e.g. evening people in Team 2).

The overall mean is strikingly similar; 316.2 minutes of sleep under the original conditions versus 315.5 minutes under the alternative conditions.

Figure 6. Total minutes of sleep per 24h period for different diurnal types in both Team 1 (T1) and Team 2 (T2).
(Note that the overall mean shows hardly any difference.)



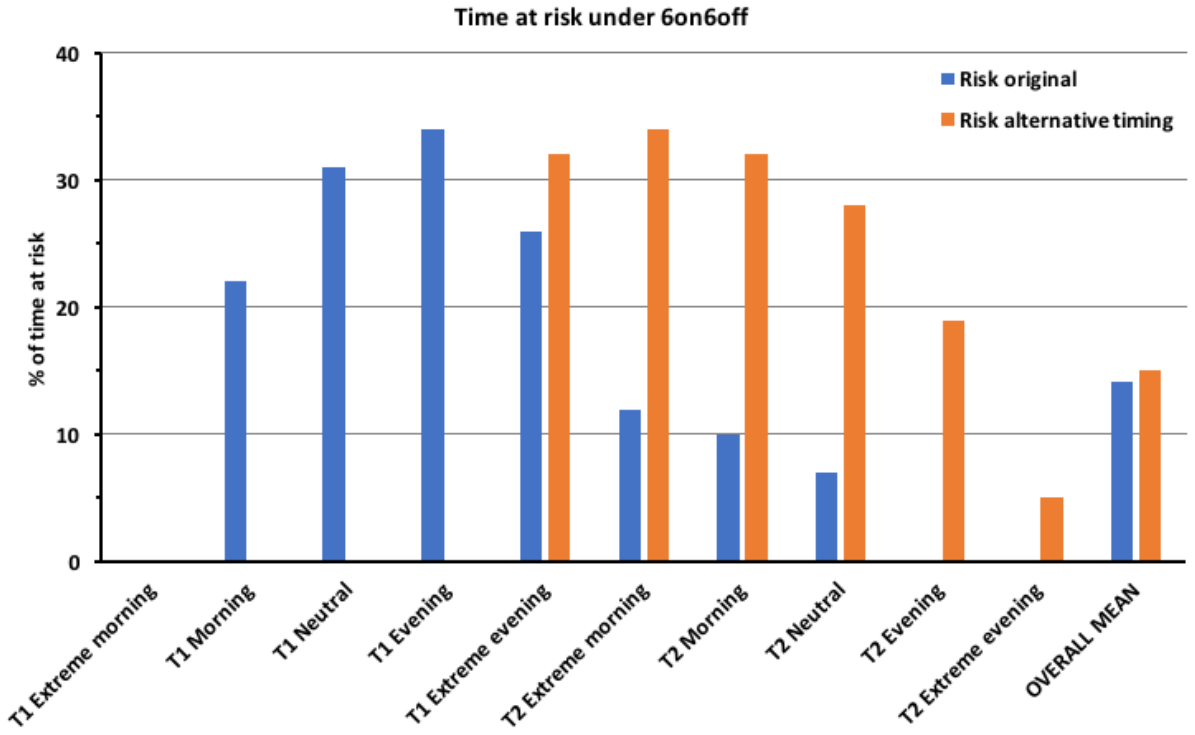


Figure 7. Percentage of time at risk for different diurnal types.
(Note 1: that a change in the watch timings mainly results in a shift of risk from team 1 towards team 2 leaving the overall mean unaffected.
Note 2: Where there is zero risk, for example, for T1 extreme morning types, there is no column)

Time at risk under the original versus the alternative timings is similarly plotted in Figure 7. It clearly shows that the overall mean risk is not affected; 14.2% under the original timings versus 15% under the alternative timings. However, a clear shift of risk from Team 1 towards Team 2 is observed.

The introduction of alternative watch handover times works better in the 12on12off system. Figure 8 shows the sleep timings and illustrates that sleep is much more equally distributed between the two watch systems, although leaving the overall mean virtually unaffected.

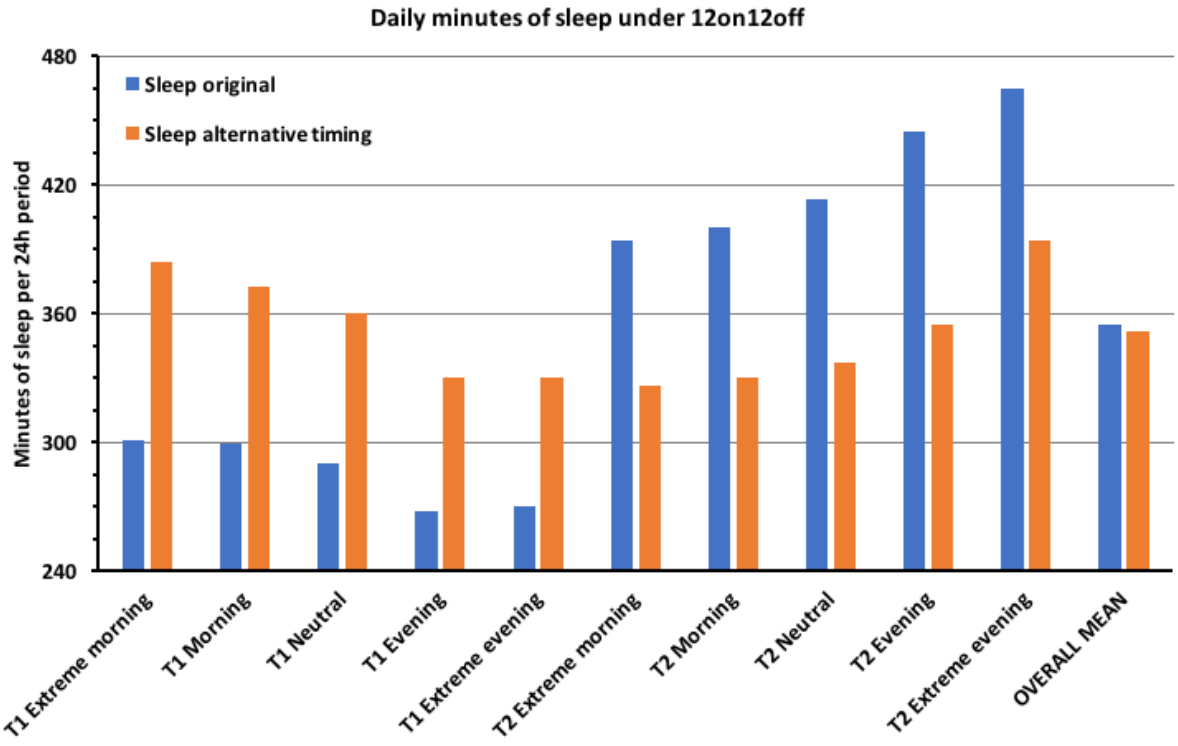


Figure 8. Total minutes of sleep per 24h period for different diurnal types in both Team 1 (T1) and Team 2 (T2).
(Note that although the overall mean hardly shows any difference, sleep is more equally distributed between the two watch teams).

Figure 9 illustrates that this more equal distribution of sleep eventually reduces the overall risk significantly. Under the original watch timings (that is 00:00 to 12:00) the overall mean risk was 23.2%. After shifting to watches from 04:00 to 16:00, the overall mean risk was10.6%.

Examples of day by day plots under both watch handover times in both systems are shown in Appendix 3.

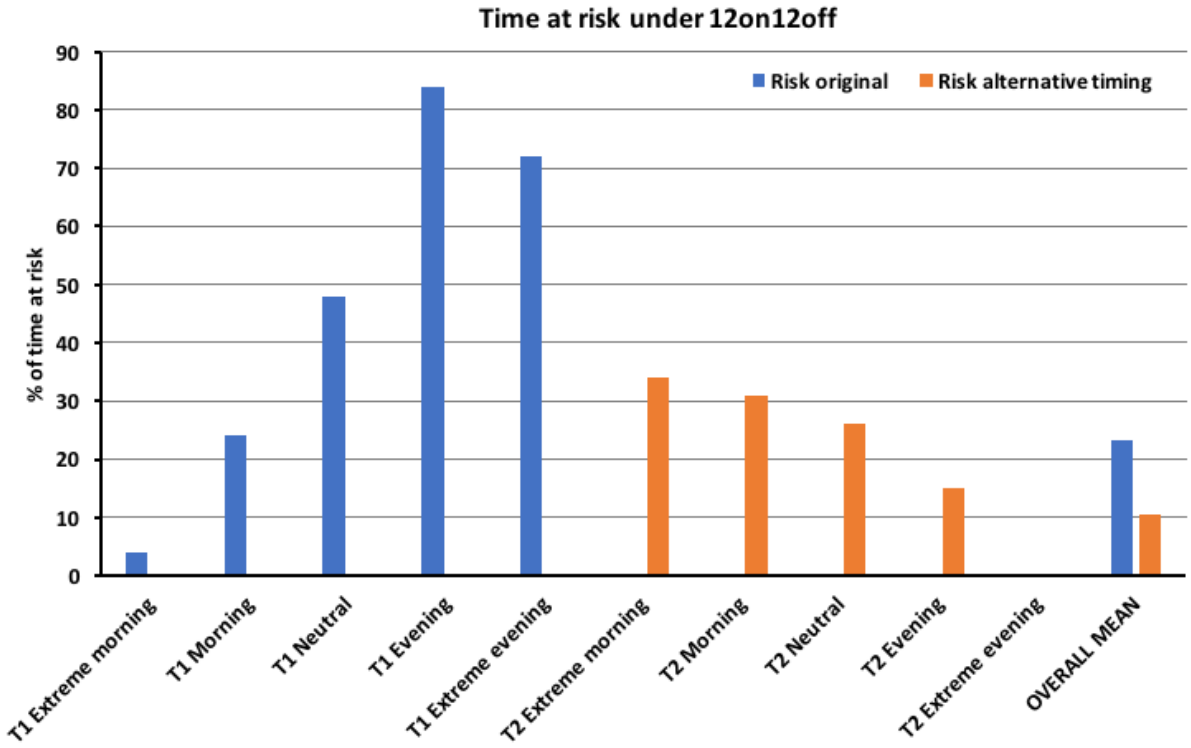


Figure 9. Percentage of time at risk for different diurnal types.
(Note 1: that a change in the watch timings not only results in a shift of risk from Team 1 towards Team 2, it even reduces the overall mean risk with more than 50%
Note 2: Where there is zero risk, for example, for T1 extreme morning types, there is no column)

3.2 Tug Crew Working hours

3.2.1 Sample and process of analysis

Hours of work data were collected from a number of different crew of various ranks working aboard different tugs of the same company. A total of 23 sets of data were made available and the work sheets covered periods from the autumn of 2016 to the first week of 2017. The weeks of data were interspersed with leave periods, so a total continuous record of the working hours of these crew was available as an input to the MARTHA software. The minimum period covered by the sheets ranged from about 4 weeks to a maximum of 9 weeks. Most individuals were working on a single tug for the whole period, but a few (mostly junior officers or deckhands) did move from one tug to another during their work periods.

Table 8 shows the different ranks and the number of records available for analysis

Table 8: Tug crew – number of different ranks

Rank	**Number**
Masters	8
Chief Officer / Mate	6
Officer of the Watch (Deck)	1
Chief Engineers	4
Officer of the Watch (Engineer)	3
Deckhand	1
TOTAL	23

Using the MARTHA software for predicting the risk of falling asleep, the objectives of the analysis were:

- To determine the risk of falling asleep during a watch period, for each participant, given their working hours and leave schedules;
- To compare these levels of risk for different circadian types, namely, evening and morning types;
- To determine the effect of reducing nap opportunities on the risk of falling asleep for both circadian types.

It should be emphasised that MARTHA provides theoretically based periods of "suggested sleeps" from which % risk of falling asleep may be evaluated. There is, of course, no evidence from the records to suggest that participants were actually able to sleep during these periods as the hours of work records do not also require completion of sleep hours. This could only be achieved through the use of Actiwatches or similar method of obtaining objective evidence. Consequently, the results can only be evaluated as a guide to the likely risk of falling asleep.

The process for achieving results was:

1 Data from each hours of work timesheet were put into the MARTHA model for each participant;

2 Using the software facility, this produced a graph for each participant. By changing the initial parameters, graphs for both evening and morning types could be produced. (Note: no information on which circadian type each participant might actually be was available.)

3 From these graphs, evaluations could be made as to the % risk of falling asleep during a work period. The evaluations were for both evening and morning types.

4 Because of the assumptions made by the software about "suggested" sleeping periods, a further step was made. This was to remove any nap under one hour from the graphs. The resulting graphs were then re-evaluated for both morning and evening types.

5 From this data, it was possible to use statistical tests to check if any of the % risk results could be produced by random chance.

Table 9 shows the results of the software modelling for each participant.

Table 9: Percentage risk of falling asleep for evening and morning types with and without naps

Rank	Days of data	% work time at risk KSS=7+ EVENING person	% work time at risk KSS=7+ MORNING person	% work time at risk NO NAP EVENING person	Change in risk as a result of NO NAP< 1 hour	% work time at risk NO NAP MORNING person	Change in risk as a result of NO NAP<1 hour
Mate	78	2%	3%	2%	0	3%	0
Mate	64	13%	11%	14%	+1	27%	+16
Mate	61	5%	5%	5%	0	5%	0
Deck OOW	60	6%	7%	6%	0	7%	0
Master	46	6%	3%	6%	0	28%	+25
C/E	46	6%	5%	6%	0	5%	0
Master	39	10%	8%	11%	+1	18%	+7
Master	38	6%	9%	6%	0	9%	0
Master	38	8%	11%	8%	0	11%	0
Master	37	3%	6%	3%	0	6%	0
Master	37	3%	1%	5%	+2	1%	0
Master	37	3%	0%	4%	+1	14%	+10
C/E	37	3%	0%	3%	0	0%	0
C/E	36	13%	15%	15%	+2	29%	+14
Engineer	36	18%	11%	20%	+2	30%	+19%
Engineer	32	7%	7%	8%	0	13%	+5
Master	31	4%	4%	4%	0	4%	0
Mate/OOW	31	1%	3%	1%	0	3%	0
OOW Eng	31	0%	0%	0%	0	0%	0
Deckhand	30	7%	3%	4%	-3	5%	+2
Mate	29	1%	4%	1%	0	4%	0
Mate	24	6%	12%	7%	+1	14%	+7
C/E	23	2%	1%	2%	0	1%	0

Table 9 shows that risk percentage levels vary from one individual to another for both evening and morning type variations, but it is notable that if naps of one hour or less are removed, the risk of falling asleep increases significantly for some morning types, as shown in red.

Table 10 presents the average daily amount of sleep and the average daily risk that the Tug personnel might experience according to their diurnal type and whether or not they were afforded the opportunity to nap. Table 10 also reports the total time at risk as a percentage of the total time worked. It is important to note that this is hypothetical, as no data on actual sleep were obtained.

As Table 10 shows, individuals who are morning types, and who are deprived the opportunity, or are unable to nap, are likely to get the least amount of daily sleep and the most at risk of experiencing a KSS ≥ 7 on a daily basis.

When the risk is expressed as a percentage of the total time worked, it can be seen that the least risk is experienced by morning types who are able to nap. Conversely, the highest risk experienced over the total time worked is for morning types who are not afforded the opportunity to nap. The total risk effectively doubles for morning types who do not nap. Furthermore, their risk of experiencing a KSS ≥ 7 is the highest of all categories and, hypothetically, for more than 10% of their working time they are at risk of experiencing micro sleeps associated with a KSS ≥ 7.

Table 10 Comparison of average daily hours of sleep, daily time at risk for morning and total percentage of time at risk for morning and evening types with and without naps

Diurnal Type	Sleep (hours: minutes/24 hours)	Risk of KSS ≥ 7 (minutes/8 hours of work)	% Risk of KSS ≥ 7 (total time worked / total time at risk)
Morning with Nap	7:02	26	5.51
Morning No Nap	6:37	50	10.22
Evening with Nap	7:05	28	5.83
Evening No Nap	7:04	29	5.83

Note. KSS = Karolinska Sleepiness Scale

The only significant difference in risk of experiencing a KSS ≥ 7 is for morning types with and without a nap. This is shown in Table 5e in Appendix 5.

4 CONCLUSIONS

The aim of this project was to examine:

the effects of working various hours of work and rest patterns, commonly found in use by Merchant Navy watch keepers.

The method used to achieve the aim was a theoretical study, which compared and analysed different watch permutations using the MARTHA fatigue prediction software tool. The analysis was able to provide the risk of falling asleep under different watch patterns. Two changes were also made to the basic watch patterns: the introduction of disruptions to off watch periods and the effect of changing the start time of different watch regimes.

A separate study also investigated the working patterns of selected tug crews. The MARTHA software was also used to input records of work hours from a number of different crew members serving on tugs and to analyse the data to provide the risk of falling asleep for different circadian types.

4.1 MN Watch Keeping Systems

The following 2-watch systems were investigated:

i. 6/6
ii. 8/8
iii. 12/12
iv. 7/5/5/7 with 2 variants
v. A Royal Navy ”dog” watch

The three 3-watch keeping systems investigated were:

1 4/8 3-watch system
2 5/5/4/5/5 – the “so-called” five and dime system
3 US submarine system: 6/6/6 starting 30 minutes earlier (eg 1130)

The analysis produced the following results:

2-watch systems can be listed with their respective percentages of the risk of falling asleep during work (1 = lowest risk; 7 = highest risk):

1.	Royal Navy system	8%
2.	7/5/5/7 v1	12.5%
	7/5/5/7 v2	12.5%
4.	6on6off	16.5%
	7/5/5/7 v3	16.5%
	8on8off	17%
7.	12on12off	27%

The 3-watch systems can be ranked as follows, based on their respective risk percentages (1 = lowest risk; 3 = highest risk):

1.	Five and dime	3%
2.	4on8off	6%
3.	US submarine (6/6/6)	16.5%

This result suggests that ships operating the “five and dime” or 4on8off systems are at a lower risk than a ship running any 2-watch system.

The vulnerability to frequently occurring sleep disruptions was tested by adding 3 hours of work in direct connection to a watch at a clock time that would arguably be most disruptive and at intervals of about 3 days. The study concluded that the amount of monthly sleep is reduced by introducing overtime work in virtually all watch systems and teams.

Altering the start time of different watch regimes does not appear to affect the overall risk for each 2-watch system, but there is a shift between the two teams in the system. The benefits for individual teams within a system affect the 12/12 system most. Individuals in teams working the 12on12off system were likely to receive the most benefit of altering the watch start time.

4.2 Tug Crew Working hours

Hours of work data were collected from a number of different crew of various ranks working aboard different tugs of the same company. A total of 23 sets of data were obtained and using the MARTHA software for predicting the risk of falling asleep, analysis determined the risk of falling asleep during a watch period for each participant. A comparison was made of these levels of risk for different circadian types, namely, evening and morning types and the effect of reducing nap opportunities on the risk of falling asleep for both circadian types.

After analysis, the study concluded that individuals who are morning types, and who are deprived the opportunity, or are unable to nap, are likely to get the least amount of daily sleep and the most at risk of experiencing a KSS ≥ 7 on a daily basis. When the risk is expressed as a percentage of the total time worked, the least risk is experienced by morning types who are able to nap. Conversely, the highest risk experienced over the total time worked is for morning types who are not afforded the opportunity to nap. Furthermore, their risk of experiencing a KSS ≥ 7 is the highest of all categories and hypothetically, for more than 10% of their working time they are at risk of experiencing micro sleeps associated with a KSS ≥ 7.

4.3 Summary of Conclusions

This study of both a variety of watch permutations and the hours of work records of selected tug crews was a pilot study to explore some of the safety issues surrounding watch keeping patterns. The results indicate that some watch systems have benefits over others and the risks of falling asleep are less. The significance of different circadian types is apparent in determining how different watches might affect individuals. Also, the disruptive impact of interruptions to rest periods has been demonstrated, as well as the benefits of changing the start time of certain watch systems. The results from the study of tug data illustrates how removing the opportunity for napping can have significant effects on the risk of falling asleep, and again the importance of a knowledge of circadian type in assessing the likely risk to safe operation. It is hoped these findings can provide useful guidance to companies

who wish to evaluate their current watch systems, and is the first step in understanding more about the risk of sleepiness in ship operations.

Appendix 1: Different 2 and 3 watch keeper systems

Traditional 4 on 8 off system:

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
0000 – 0400 (4)	Team 1	Team 1	Team 1	Team 1	Team 1	Team 1
0400 – 0800 (4)	Team 2	Team 2	Team 2	Team 2	Team 2	Team 2
0800 – 1200 (4)	Team 3	Team 3	Team 3	Team 3	Team 3	Team 3
1200 – 1600 (4)	Team 1	Team 1	Team 1	Team 1	Team 1	Team 1
1600 – 2000 (4)	Team 2	Team 2	Team 2	Team 2	Team 2	Team 2
2000 – 0000 (4)	Team 3	Team 3	Team 3	Team 3	Team 3	Team 3

Traditional 6 on 6 off system:

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
0000 – 0600 (6)	Team 1	Team 1	Team 1	Team 1	Team 1	Team 1
0600 – 1200 (6)	Team 2	Team 2	Team 2	Team 2	Team 2	Team 2
1200 – 1800 (6)	Team 1	Team 1	Team 1	Team 1	Team 1	Team 1
1800 – 0000 (6)	Team 2	Team 2	Team 2	Team 2	Team 2	Team 2

Traditional 12 on 12 off system:

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
0000 – 1200 (12)	Team 1	Team 1	Team 1	Team 1	Team 1	Team 1
1200 – 0000 (12)	Team 2	Team 2	Team 2	Team 2	Team 2	Team 2

Traditional 8 on 8 off system:

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
0400 – 1200 (8)	Team 1	Team 2	Team 1	Team 2	Team 1	Team 2
1200 – 2000 (8)	Team 2	Team 1	Team 2	Team 1	Team 2	Team 1
2000 – 0400 (8)	Team 1	Team 2	Team 1	Team 2	Team 1	Team 2

Original (USCG) 7/5/5/7 system:

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
0000 – 0500 (5)	Team 1	Team 1	Team 1	Team 1	Team 1	Team 1
0500 – 1200 (7)	Team 2	Team 2	Team 2	Team 2	Team 2	Team 2
1200 – 1900 (7)	Team 1	Team 1	Team 1	Team 1	Team 1	Team 1
1900 – 0000 (5)	Team 2	Team 2	Team 2	Team 2	Team 2	Team 2

The Danish 7/5/5/7 system:

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
0100 – 0800 (7)	Team 1	Team 1	Team 1	Team 1	Team 1	Team 1
0800 – 1300 (5)	Team 2	Team 2	Team 2	Team 2	Team 2	Team 2
1300 – 1800 (5)	Team 1	Team 1	Team 1	Team 1	Team 1	Team 1
1800 – 0100 (7)	Team 2	Team 2	Team 2	Team 2	Team 2	Team 2

Warships 7/5/5/7 system:

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
0000 – 0700 (7)	Team 1	Team 1	Team 1	Team 1	Team 1	Team 1
0700 – 1200 (5)	Team 2	Team 2	Team 2	Team 2	Team 2	Team 2
1200 – 1700 (5)	Team 1	Team 1	Team 1	Team 1	Team 1	Team 1
1700 – 0000 (7)	Team 2	Team 2	Team 2	Team 2	Team 2	Team 2

Royal Navy ”dog-watch” system:

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
0000 – 0400 (4)	Team 1	Team 2	Team 1	Team 2	Team 1	Team 2
0400 – 0800 (4)	Team 2	Team 1	Team 2	Team 1	Team 2	Team 1
0800 – 1200 (4)	Team 1	Team 2	Team 1	Team 2	Team 1	Team 2
1200 – 1600 (4)	Team 2	Team 1	Team 2	Team 1	Team 2	Team 1
1600 – 1800 (2)	Team 1	Team 2	Team 1	Team 2	Team 1	Team 2
1800 – 2000 (2)	Team 2	Team 1	Team 2	Team 1	Team 2	Team 1
2000 – 0000 (4)	Team 1	Team 2	Team 1	Team 2	Team 1	Team 2

Five and dime system:

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
2200 – 0200 (4)	Team 1	Team 3	Team 2	Team 1	Team 3	Team 2
0200 – 0700 (5)	Team 2	Team 1	Team 3	Team 2	Team 1	Team 3
0700 – 1200 (5)	Team 3	Team 2	Team 1	Team 3	Team 2	Team 1
1200 – 1700 (5)	Team 1	Team 3	Team 2	Team 1	Team 3	Team 2
1700 – 2200 (5)	Team 2	Team 1	Team 3	Team 2	Team 1	Team 3

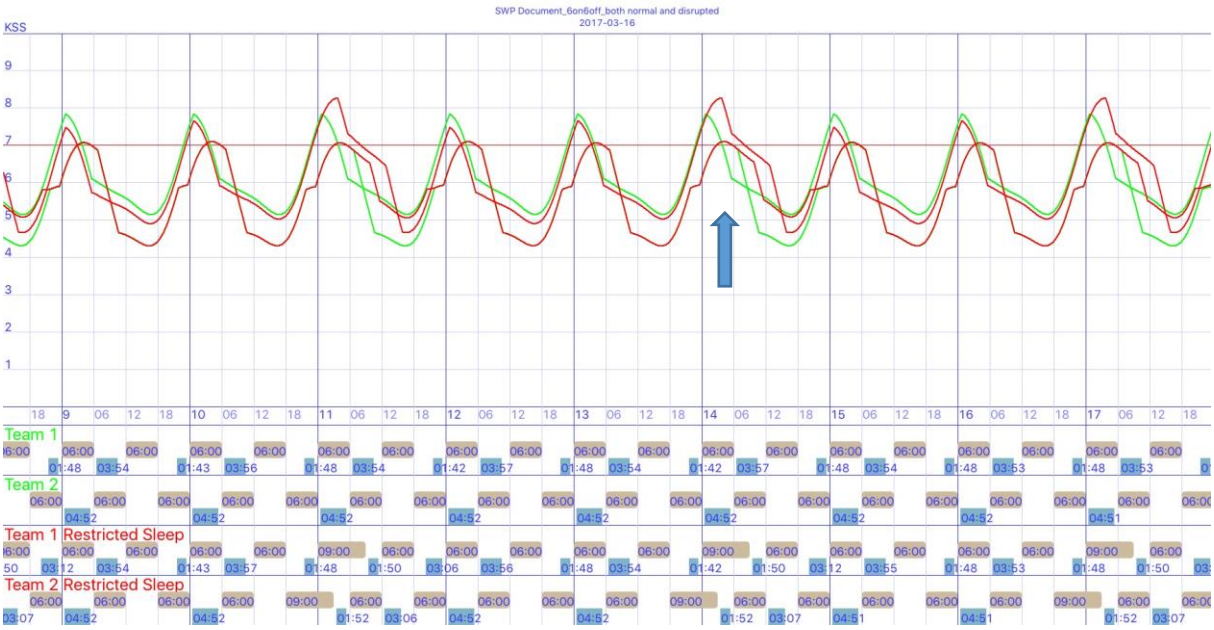
US submarine system:

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
2330 – 0530 (6)	Team 1	Team 2	Team 3	Team 1	Team 2	Team 3
0530 – 1130 (6)	Team 2	Team 3	Team 1	Team 2	Team 3	Team 1
1130 – 1730 (6)	Team 3	Team 1	Team 2	Team 3	Team 1	Team 2

Appendix 2: Normal watch timings versus overtime work

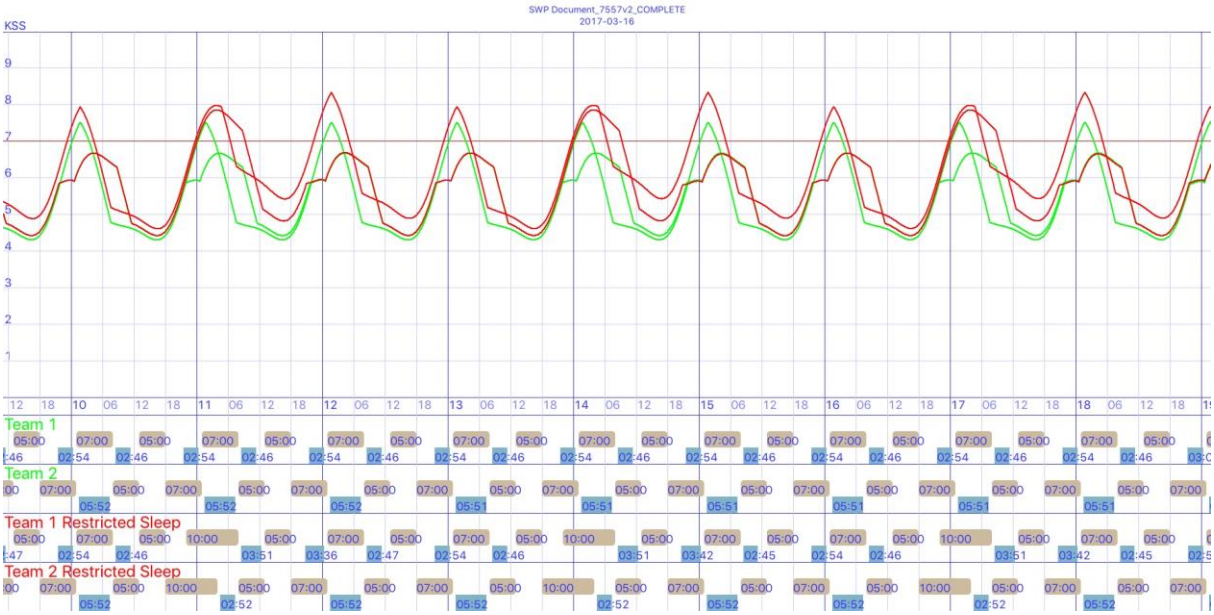
Sleepiness plots under normal timings are indicated by green lines, after overtime work in red lines.

6on6off – morning types:



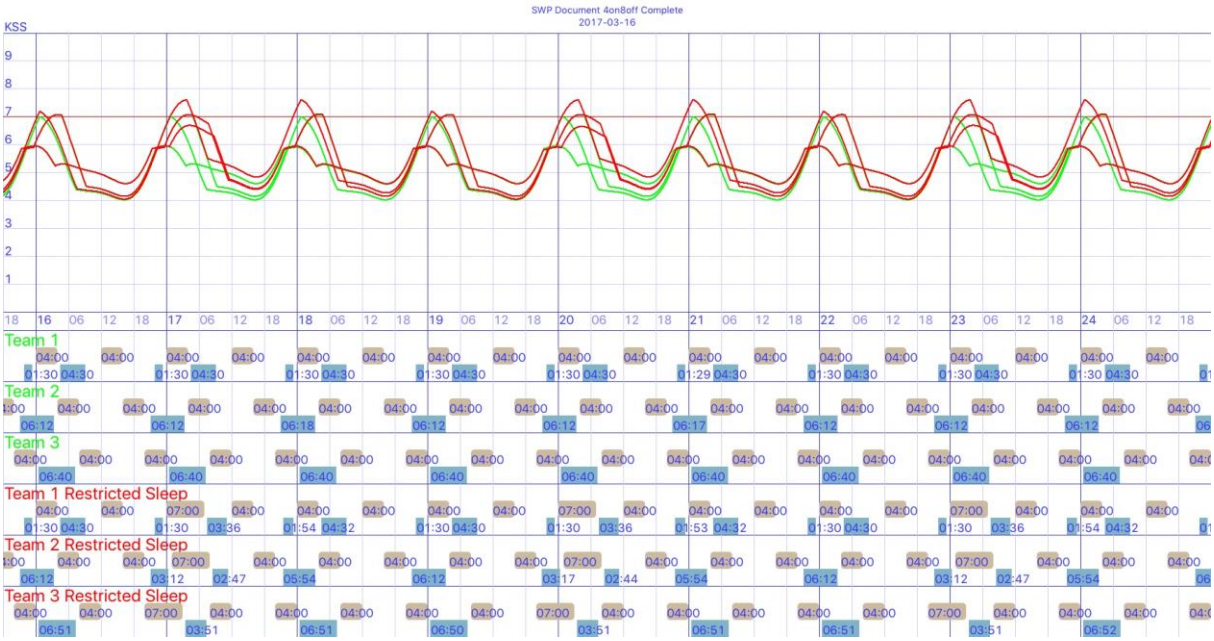
Although clear elevations in sleepiness are to be seen in the overtime (sleep restricted) condition directly following/during the overtime work, at some points the sleep restricted conditions result in increased alertness (at the blue arrow). This is because team 2 normally doesn't sleep between 12:00 and 18:00. The overtime work, however, makes him/her so sleepy that he/she will now be able to sleep at that time, resulting in subsequent increased alertness/reduced sleepiness

7557v2 – morning types:



The red lines of the restricted sleep condition are clearly either on top or above the green lines of the normal condition. Not only directly after the restricted sleep periods, but continuously.

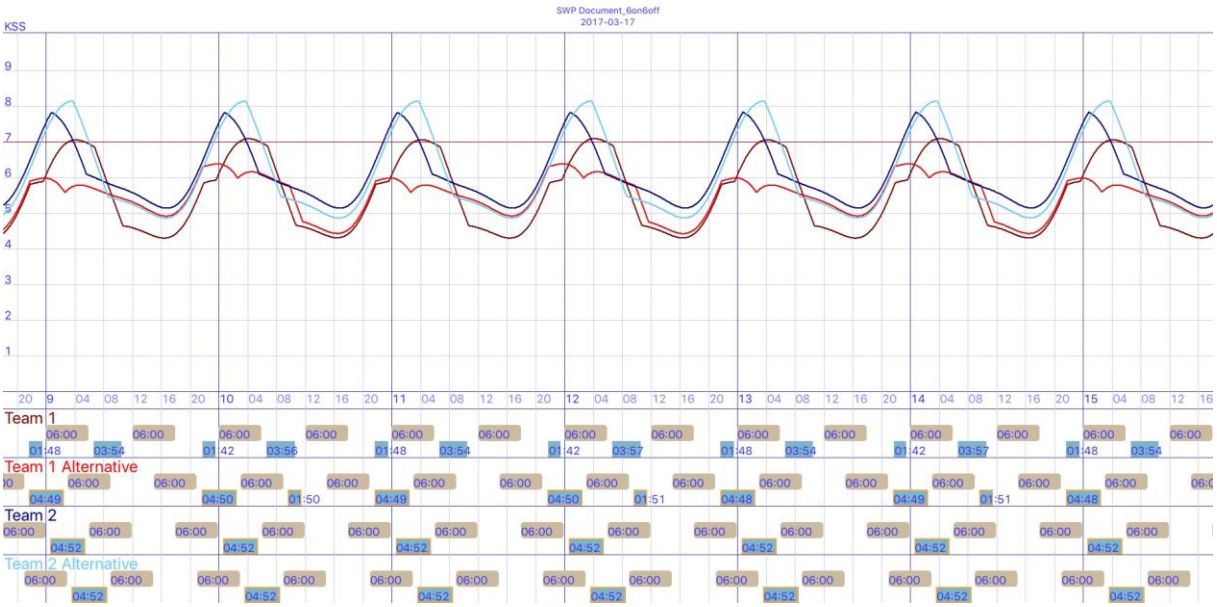
4on8off – morning types:



Again, the diagram illustrates almost continuously higher sleepiness levels in the restricted sleep conditions than under normal conditions

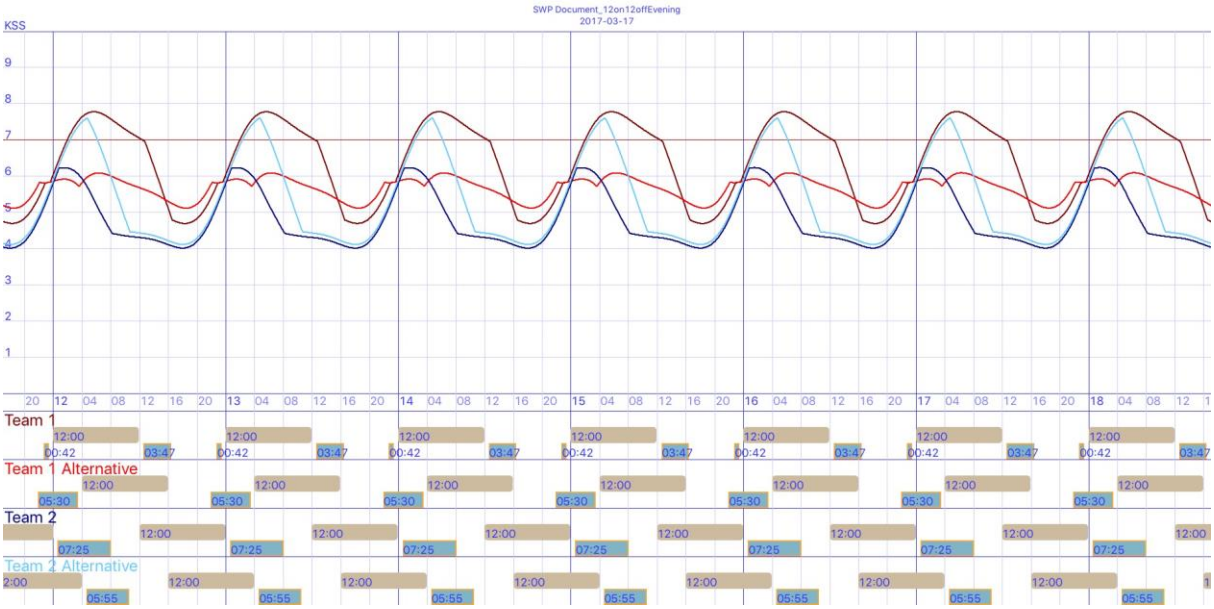
Appendix 3: Normal versus alternative watch handover times

6on6off – morning types:



The two watch teams under the original timings are shown in dark red and dark blue, while the alternative watch handover times are plotted in light red and light blue.

12on12off – evening types:

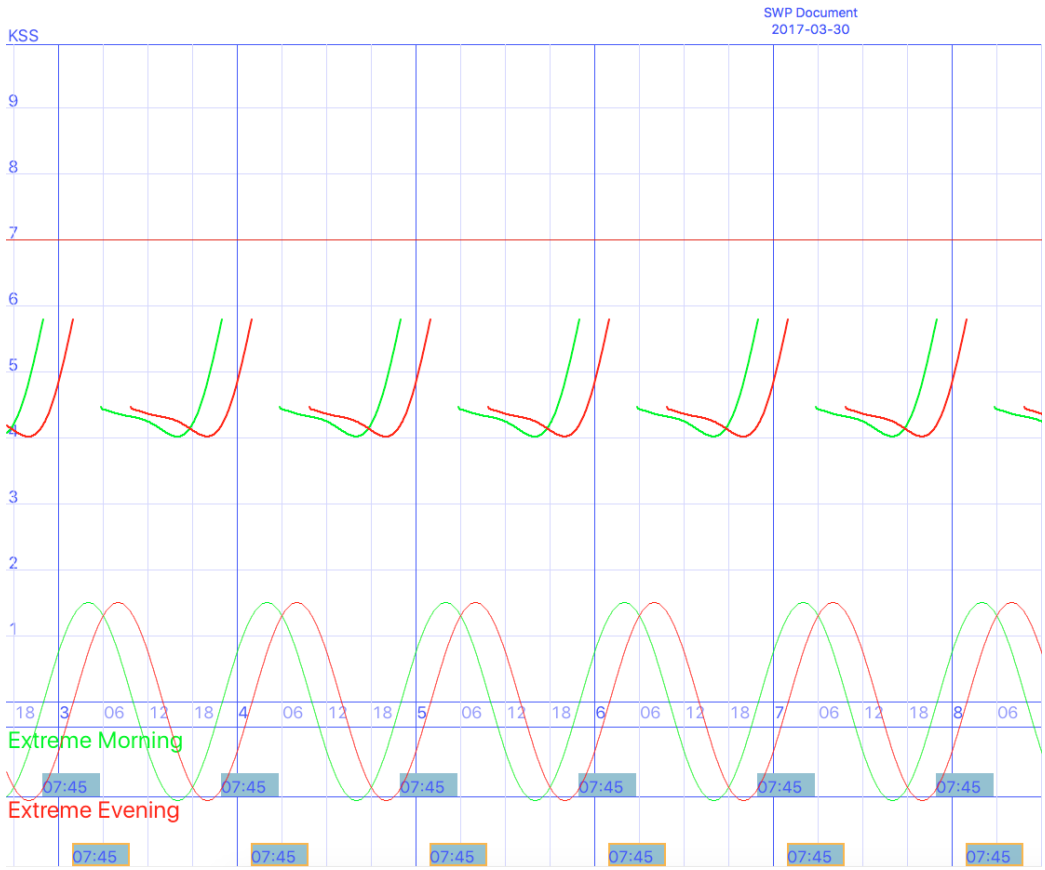


The two watch teams under the original timings are shown in dark red and dark blue, while the alternative watch handover times are plotted in light red and light blue.

Appendix 4: Description of different circadian types

Morning types wake up early and are at their best during the first part of the day. They eat breakfast and prefer to retire relatively early after a light dinner.
Evening types feel best and most alert during late hours They prefer to have their main meal late in the day and usually skip breakfast. A cup of coffee is often their morning meal. But they do need an alarm clock in the morning to ensure they rise to meet their daily obligations.

Evening types predominate because humans have an inner clock with a period slightly longer than 24 hours. That causes a tendency to stay up a bit later and wake up later each day. Interestingly, however, morning types tend to predominate among seafarers, as shown in project MARTHA. Evening and morning type tendencies are natural and are not considered problems.



An illustration of morning and evening types. The bottom sinusoidal curves display the endogenous 24h variation in alertness whereas the upper curves show sleepiness during the day assuming each type is sleeping at its respective times.

Appendix 5: Tables of significant differences of time at risk

Note: In all the tables, the nomenclature of "n.s." - not significant statistically

Table 5a. Significant differences between daily time at risk for morning types in all 2-watch systems.

	Royal Navy	**12on12off**	**7/5/5/7 v3**	**7/5/5/7 v1**	**6on6off**	**8on8off**
7/5/5/7 v2	p<.005	p<.0001	p<.0001	p<.0001	p<.0001	p<.0001
	Royal Navy	p<.05	p<.05	p<.005	p<.0001	p<.0001
		12on12off	n.s.	n.s.	p<.05	p<.0005
			7/5/5/7 v3	n.s.	p<.05	p<.0005
				7/5/5/7 v1	n.s.	p<.005
					6on6off	n.s.

Table 5b Significant differences between daily time at risk for evening types in all 2-watch systems.

Royal Navy	**7/5/5/7 v1**	**8on8off**	**6on6off**	**7/5/5/7 v2**	**7/5/5/7 v3**	**12on12off**
Royal Navy	p<.05	p<.0001	p<.0001	p<.0001	p<.0001	p<.0001
	7/5/5/7 v1	n.s.	p<.01	p<.0001	p<.0001	p<.0001
		8on8off	n.s.	p<.005	p<.005	p<.0001
			6on6off	n.s.	n.s.	p<.0001
				7/5/5/7 v2	n.s.	p<.0001
					7/5/5/7 v3	p<.0001

Table 5c. Overall significant difference between daily time at risk in all 2-watch systems.

Royal Navy	**7/5/5/7 v1**	**7/5/5/7 v2**	**6on6off**	**7/5/5/7 v3**	**8on8off**	**12on12off**
Royal Navy	p<.005	p<.005	p<.0001	p<.0001	p<.0001	p<.0001
	7/5/5/7 v1	n.s.	p<.05	p<.05	p<.05	p<.0001
		7/5/5/7 v2	p<.05	p<.05	p<.05	p<.0001
			6on6off	n.s.	n.s	p<.0001
				7/5/5/7 v3	n.s	p<.0001
					8on8off	p<.0001

Table 5d. Significant differences between daily time at risk for morning types in all 3-watch systems.

Morning types	**4on8off**	**Five and dime**	**US submarine**
	4on8off	n.s.	p<.0001
		Five and dime	p<.0001
Evening types	**Five and dime**	**4on8off**	**US submarine**
	Five and dime	p<.0001	p<.0001
		4on8off	p<.0001
Overall mean	**Five and dime**	**4on8off**	**US submarine**
	Five and dime	p<.05	p<.0001
		4on8off	p<.0001

Table 5e Significant differences in average daily time at risk for morning and evening types with and without naps for tug crew.

Morning	**Evening**	**Morning No Nap**	**Evening No Nap**
Morning	*n.s.*	p<.05	*n.s.*
	Evening	*n.s.*	*n.s.*
		Morning No Nap	*n.s.*