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Alternative Submarine Watch Systems:

Recommendation for a new CF submarine watch schedule

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Abstract

Background. The summer 2007 at-sea trial to evaluate the Canadian Forces (CF) submarine watch schedule revealed dangerously low levels of modeled cognitive effectiveness among the crew. In response, Defence Research and Development (DRDC) Toronto hosted an International Submarine Watch Schedule Symposium (CF, USN (United States Navy), RN (Royal Navy), RAN (Royal Australian Navy), and RNLN (Royal NetherLands Navy)) to review International experience with National watch schedule challenges and to model alternative watch schedules that would be more sparing of crew performance. **Methods.** Three alternative watch schedule systems were modeled (1-in-3 straight eights, 1-in-3 straight fours, and 1-in-2 (8on-4off-4on-8off)). These three alternative watch systems were compared to the current 1-in-2 (6on-6off-6on-6off) CF submarine watch schedule. **Results.** The mean modeled cognitive effectiveness for all watches within each system were 96%, 96%, 89% and 66% for the 1-in-3 straight eights, 1-in-3 straight fours, 1-in-2 (8-4-4-8) and the current CF 1-in-2 (6-6-6-6), respectively. **Discussion**. While it is evident that the best of these alternative watch schedules are the 1-in-3 straight eights and 1-in-3 straight fours (both resulting in 96% mean cognitive effectiveness), it is also evident that only larger submarines with larger crews (nuclear-powered USN and RN ballistic missile submarines and nuclear-powered USN attack submarines) can employ such a watch system. Smaller diesel-powered attack submarines have small crews which makes it impossible for such boats to operate either the 1-in-3 straight eights or the 1-in-3 straight fours. Essentially, small diesel-powered submarines must employ a 1-in-2 watch system (i.e., work 12 hours each day). The current CF submarine system is 1-in-2 and involves two 6-hour daily watch periods for each of the ‘front’ and ‘back’ syndicates. The alternative 1-in-2 (8-4-4-8) watch schedule has an 8-hour and a 4-hour daily watch period for each of the ‘port’ and ‘starboard’ syndicates. This alternative 1-in-2 (8-4-4-8) watch system is almost as good as the 1-in-3 straight eights or 1-in-3 straight fours (i.e., mean overall cognitive effectiveness of 89% for the 1-in-2 (8-4-4-8) system vs. 96% for each of the 1-in-3 straight eights or the 1-in-3 straight fours systems), and much better than the overall 66% mean cognitive effectiveness of the current 1-in-2 (6-6-6-6) watch system. **Conclusion**. The alternative 1-in-2 watch system represents a 23% overall increase in cognitive effectiveness over the current 1-in-2 watch system. **Recommendations.** The 1-in-2 (8-4-4-8) watch system should be evaluated in an at-sea trial with a view to adapting operational routines to that watch system, and, if possible, the system should be incorporated on all CF submarines.

Résumé

Contexte. Un essai en mer réalisé à l’été 2007 afin d’évaluer l’horaire de garde à bord des sous-marins des FC a révélé des niveaux dangereusement faibles d’efficacité cognitive des membres de l’équipage. Dans la foulée de ces résultats, RDDC Toronto a organisé un symposium international sur les horaires de garde à bord des sous-marins (FC, USN, RN, RAN et RNLN) permettant de faire le point sur la façon dont les différents pays relèvent les défis imposés par leurs horaires de garde et de préparer des modèles d’horaires qui hypothéqueraient moins le rendement de l’équipage. **Méthodologie** : Trois horaires différents ont été préparés [1 tour sur 3 de huit heures, 1 tour sur 3 de quatre heures, et 1 tour sur 2 (8-4-4-8)]. Ces trois horaires possibles ont été comparés au système actuel de 1 tour sur 2 (6-6-6-6) en vigueur à bord des sous-marins des FC.

Résultats : L'efficacité cognitive moyenne observée des sous-mariniers durant tous les tours de garde de chaque système s'est établie à 96 %, 91 % et 89 %, et à 66 % pour les tours de garde 1 sur 3 de huit heures, 1 sur 3 de quatre heures, 1 sur 2 (8-4-4-8) et le tour 1 sur 2 (6-6-6-6) actuel des FC, respectivement. **Analyse**. Bien que l'horaire de garde alternatif de 1 tour sur 3 de huit heures soit manifestement le meilleur des trois horaires proposés (efficacité moyenne de 96 %), on a constaté que seuls les gros sous-marins dotés d'équipages plus nombreux (sous-marins à propulsion nucléaire de la USN, sous-marins lance-missiles balistiques de la RN et sous-marins d'attaque à propulsion nucléaire de la USN) appliquent cet horaire. Les petits sous-marins d'attaque à propulsion diésel ont des équipages réduits, ce qui les empêche d'utiliser un horaire de garde de 1 tour sur 3 de huit heures ou de 1 tour sur trois de quatre heures. Essentiellement, les petits sous-marins à propulsion diésel doivent utiliser un horaire de garde de 1 tour sur 2 (soit 12 heures ouvrables par jour). L'horaire de garde en usage à bord des sous-marins des FC est le 1 tour sur 2 qui suppose deux périodes de garde de six heures chaque jour pour les équipes de l'avant et de l'arrière. L'horaire de garde alternatif de 1 tour sur 2 (8-4-4-8) comporte des périodes de huit et de quatre heures chaque jour pour chacune des équipes de bâbord et de tribord. Cette solution équivaut presque à l'horaire de 1 tour sur 3 de quatre heures et 1 tour sur 3 de huit heures (efficacité cognitive moyenne de 89 % pour l'horaire de 1 tour sur 2 (8-4-4-8) comparativement à une efficacité cognitive de 96 % pour l'horaire de 1 tour sur trois de quatre heures ainsi que pour l'horaire de 1 tour sur trois de huit heures) et elle est de beaucoup supérieure à l'horaire de garde actuel de 1 tour sur 2 (6-6-6-6) dont l'efficacité cognitive moyenne est de 66 %. **Conclusion**. L'horaire de garde alternatif qui consiste à servir 1 tour sur 2 correspond à un accroissement global de 23 % de l'efficacité cognitive par rapport à l'horaire actuel de 1 tour sur 2. **Recommandations.** On devrait évaluer l'horaire de garde à 1 tour sur 2 (8-4-4-8) dans le cadre d'un essai en mer dans l'optique d'y adapter les tâches quotidiennes courantes et, si c'est possible, appliquer cet horaire à tous les sous-marins des FC.

Executive summary

Alternative Submarine Watch Systems: Recommendation for a new CF submarine watch schedule

Michel Paul; Steven Hursh; James Miller; DRDC Toronto TR 2010-001; Defence R&D Canada – Toronto; January 2010.

Background: Advances in our understanding of shift work schedules over the last 20 years have indicated that certain schedules can lead to poor sleep and impairment of on-the-job performance. Evaluation of Canadian Forces (CF) submarine watch schedules in 2007 revealed chronically impaired sleep and dangerously low levels of modeled cognitive effectiveness among the crew. In response, Defence Research and Development (DRDC) Toronto hosted an International Submarine Watch Schedule Symposium (CF, USN (United States Navy), RN (Royal Navy), RAN (Royal Australian Navy), and RNLN (Royal NetherLands Navy)) to review International experience with National watch schedule challenges and to model alternative watch schedules that would be more sparing of crew performance.

Methods: Based on general principles of sleep science, the group evaluated three alternative watch schedules. The three alternative watch schedule systems that were modeled were a 1-in-3 straight eights requiring three watch syndicates, a similar 1-in-3 straight fours, and a 1-in-2 (8on-4off-4on-8off) schedule requiring only two watch syndicates. These three alternative watch systems were compared to the current 1-in-2 (6on-6off-6on-6off) CF submarine watch schedule. The schedules were evaluated with a validated sleep and fatigue modeling system shown to accurately predict cognitive performance and accident risk in civilian work settings and performance in military populations (Fatigue Avoidance Scheduling Tool (FAST™) modeling software). Predicted performance ranges from 100% (normal best for a well-rested person) to a worst case of 0%. For comparison purposes, an effectiveness score of 70% is about equivalent to Blood Alcohol Content (BAC) of 0.08% in terms of its effects on reaction time.

Results: The mean modeled cognitive effectiveness for all watches within each system were 96%, 96%, 89% and 66% for the 1-in-3 straight eights, 1-in-3 straight fours, 1-in-2 (8-4-4-8) and the current CF 1-in-2 (6-6-6-6), respectively.

Discussion: It was evident that the 1-in-3 straight eights was the best of the alternative watches modeled. It was also evident that only larger submarines with large crews divided into three watch syndicates (nuclear-powered USN and RN ballistic missile submarines and nuclear-powered USN attack submarines) could employ such a watch system. Smaller diesel-powered attack submarines have small crews which make it impossible for such boats to operate either the 1-in-3 straight eights or the 1-in-3 straight fours. Essentially, small diesel-powered submarines must employ a 1-in-2 watch system with two syndicates that work a total of 12 hours each day. The current CF submarine system is 1-in-2 and involves two 6-hour daily watch periods for each of the 'front' and 'back' syndicates. The alternative 1-in-2 (8-4-4-8) watch schedule has an 8-hour and a 4-hour daily watch period for each of the 'port' and 'starboard' syndicates. Based on the modeled performance results, this alternative 1-in-2 (8-4-4-8) watch system is almost as good as the 1-in-3 straight eights or 1-in-3 straight fours, with a mean overall cognitive effectiveness of 89% for the 1-in-2 (8-4-4-8) system compared to a mean overall effectiveness of 96% for each of

the 1-in-3 straight eights or 1-in-3 straight fours system. By comparison, the modeled results of the proposed 1-in-2 (8-4-4-8) system (having an overall mean cognitive effectiveness of 89%) are much better than the overall 66% mean cognitive effectiveness of the current 1-in-2 (6-6-6-6) watch system.

Conclusion: The conclusion of the study group was that the alternative 1-in-2 watch system appears to represented a 23% overall increase in cognitive effectiveness over the current 1-in-2 watch system.

Future plans It was recommended that the 1-in-2 (8-4-4-8) watch system should be evaluated in an at-sea trial with a view to adapting operational routines to that watch system, and, if possible, the system should be incorporated on all CF submarines.

Sommaire

Systèmes différents d'horaire de garde à bord des sous-marins : nouvel horaire recommandé pour les sous-marins des FC

Michel Paul, Steven Hursh, James Miller, RDDC Toronto RT 2010-001; R et D pour la défense Canada – Toronto; janvier 2010.

Contexte : Les découvertes des 20 dernières années dans le domaine des horaires de travail par quart indiquent que certains horaires peuvent nuire au sommeil et hypothéquer le rendement au travail. L'évaluation des horaires de garde à bord des sous-marins des FC réalisée en 2007 a révélé des problèmes chroniques de sommeil et des niveaux dangereusement faibles d'efficacité cognitive chez les membres de l'équipage. Dans la foulée de ces résultats, RDDC Toronto a organisé un symposium international sur les horaires de garde à bord des sous-marins (FC, USN, RN, RAN et RNLN) permettant de faire le point sur la façon dont les différents pays relèvent les défis imposés par leurs horaires de garde et de préparer des modèles d'horaires qui hypothéqueraient moins le rendement de l'équipage.

Méthodologie : En se fondant sur les principes généraux de la science du sommeil, le groupe de chercheurs a évalué trois horaires de garde différents, soit l'horaire à 1 tour sur trois de huit heures exigeant trois équipes de garde, l'horaire à 1 tour sur trois de quatre heures et l'horaire à 1 tour sur 2 (8-4-4-8) exigeant seulement deux équipes de garde. Ces trois horaires possibles ont été comparés à l'horaire à 1 tour sur 2 (6-6-6-6) actuellement en usage à bord des sous-marins des FC. Ils ont été évalués au moyen d'un système validé de modélisation du sommeil et de la fatigue reconnu pour la qualité de ses prévisions du rendement cognitif et des risques d'accident en milieux de travail civils et du rendement des effectifs militaires (logiciel de modélisation SAFTE/FAST). Les taux de rendement prévus allaient de 100 % (meilleur sommeil) à 0 % (pire sommeil). Pour la comparaison, un taux d'efficacité de 70 % équivaut à peu près à un taux d'alcoolémie de 0,08 en ce qui concerne les effets sur le temps de réaction.

Résultats : L'efficacité cognitive moyenne observée des sous-mariniers durant tous les tours de garde de chaque système s'est établie à 96 %, 96 % et 89 %, et à 66 % pour les tours de garde 1 sur 3 de huit heures, 1 sur 3 de quatre heures, 1 sur 2 (8-4-4-8) et le tour 1 sur 2 (6-6-6-6) actuel des FC, respectivement.

Analyse : L'horaire de garde alternatif de 1 tour sur 3 de huit heures est manifestement le meilleur des trois horaires proposés. On a aussi constaté que seuls les gros sous-marins dotés d'équipages plus nombreux (sous-marins à propulsion nucléaire de la USN, sous-marins lance-missiles balistiques de la RN et sous-marins d'attaque à propulsion nucléaire de la USN) pouvaient appliquer cet horaire. Les petits sous-marins d'attaque à propulsion diésel ont des équipages réduits, ce qui les empêche d'utiliser un horaire de garde de 1 tour sur 3 de huit heures ou de 1 tour sur trois de quatre heures. Essentiellement, les petits sous-marins à propulsion diésel doivent utiliser un horaire de garde de 1 tour sur 2 et deux équipes de garde travaillant 12 heures par jour. L'horaire de garde en usage à bord des sous-marins des FC est le 1 tour sur 2, qui suppose deux périodes de garde de six heures chaque jour pour les équipes de l'avant et de l'arrière. L'horaire de garde alternatif de 1 tour sur 2 (8-4-4-8) comporte des périodes de huit et de quatre heures chaque jour pour chacune des équipes de bâbord et de tribord. Selon la

modélisation du rendement, cette solution équivaut presque à l'horaire de 1 tour sur 3 de quatre heures ou l'horaire de 1 tour sur 3 de huit heures, l'efficacité cognitive moyenne étant de 89 % pour l'horaire de 1 tour sur 2 (8-4-4-8) comparativement à une efficacité cognitive de 96 % pour l'horaire de 1 tour sur trois de quatre heures ainsi que pour l'horaire de i tour sur trois de huit heures. Par comparaison, ces résultats sont de beaucoup supérieurs à l'horaire de garde actuel à 1 tour sur 2 (6-6-6-6) dont l'efficacité cognitive moyenne est de 66 %.

Conclusion : Le groupe d'étude a conclu que l'horaire de garde alternatif qui consiste à servir 1 tour sur 2 semble correspondre à un accroissement global de 23 % de l'efficacité cognitive par rapport à l'horaire actuel de 1 tour sur 2.

Perspectives : On devrait évaluer l'horaire de garde à 1 tour sur 2 (8-4-4-8) dans le cadre d'un essai en mer dans l'optique d'y adapter les tâches quotidiennes courantes et, si c'est possible, appliquer cet horaire à tous les sous-marins des FC.

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1 Background

As a follow-on to our FAST™ (Fatigue Avoidance Scheduling Tool) modeling to determine cognitive effectiveness of the crew in support of the Board of Inquiry (BOI) investigating the October 2005 fire on Her Majesty's Canadian Ship (HMCS) Chicoutimi, the Canadian Forces (CF) submarine community tasked the Defence Research and Development Canada – Toronto (DRDC – Toronto) to conduct an at-sea evaluation of the submarine watch schedule (Paul et al. 2008) on HMCS Corner Brook. The inputs to FAST™ are two streams of data; daily sleep (ideally actigraphically-measured sleep) and daily duty hours. An actigraph is a small accelerometer about the size of a wrist watch and is worn on the wrist. Based on a reduction algorithm, an actigraph provides a motion-based estimate of daily sleep quantitatively to the nearest minute for extended periods. The output of FAST™ is cognitive effectiveness, a metric proportional to reaction time on a test of cognitive vigilance.

The results of the at-sea trial revealed that the current watch schedule results in even more serious attrition of submariner performance than expected as based on the preliminary models generated in support of the HMCS Chicoutimi BOI. In response to the knowledge gained from the at-sea trial an International Submarine Watch Schedule Symposium was hosted with some of our allies (Royal Navy (RN), United States Navy (USN), Royal Australian Navy (RAN), and Royal NertherLands Navy (RNLN) in September 2009. The purpose of the Watch Schedule Symposium was to share submarine watch schedule challenges amongst the participating countries and to model some alternative schedules which would be more sparing of cognitive effectiveness in our submarine crews. The focus of this report is to document the alternative watch schedules developed at the Watch Schedule Symposium.

2 Methods

2.1 FAST™ Modeling Program

A description of the FAST™ model is provided in Annex F. FAST™ graphs are shown in Annex B for the 3 watch syndicates of the 1-in-3 straight eights, Annex C for the 3 syndicates of the 1-in-3 straight fours, Annex D for the 2 syndicates of the 1-in-2 (8-4-4-8) watch (proposed for the CF submarine service), and Annex E for the 2 syndicates of the 1-in-2 (6-6-6-6) watch (currently in use in CF submarines). Some details regarding these graphs are as follows:

- The vertical axis on the left side of the FAST™ graphs represents human cognitive performance effectiveness as a percentage of optimal performance (100%). Effectiveness has a range from 100 (normal best) to 0 (worst case). The oscillating line in the diagram represents average performance (cognitive effectiveness) as determined by time of day, biological rhythms, time spent awake, and amount of sleep.
- The dotted line which is below the cognitive effectiveness curve and follows a similar oscillating pattern as the cognitive effectiveness curve represents the 10th percentile of cognitive effectiveness.
- The green band (from 90% to 100%) represents acceptable cognitive performance effectiveness for workers conducting safety sensitive jobs (flying, driving, weapons operation, command and control, etc.).
- The yellow performance band (from 65% to 90% cognitive effectiveness) indicates caution. Personnel engaged in skilled performance activities such as aviation should not be allowed to operate within this performance band.
- The area from the dotted line to the pink area represents the cognitive effectiveness equivalent to the circadian nadir and a second day without sleep.
- The pink performance band (below 65%) represents performance effectiveness after 2 days and a night of sleep deprivation. Under these conditions, no one can be expected to function well on any task.
- A value of 77% cognitive effectiveness corresponds to a blood alcohol content (BAC) of 0.05% (legally impaired in some jurisdictions). A value of 70% cognitive effectiveness corresponds to a BAC of 0.08% (legally impaired in most jurisdictions). These BAC equivalency levels associated with sleep deprivation/fatigue are based on three important studies (Arnedt et al. 2001; Dawson and Reid 1997; Lamond and Dawson 1999).
- The abscissa (x-axis) illustrates periods of work (red bars), sleep (blue bars), darkness (gray bars) and time of day in hours.
- The red triangles labelled C1 and C2 (on the 2 models representing the current CF submarine watch system) located just above the abscissa are event markers indicating when the submarine left port (1100 hours Zulu time on June 26, 2007) and when the submarine submerged and regular watches began (1700 hours Zulu time on June 27, 2007).

- The red line represents acrophase and is related to the right-hand vertical scale (in hours). For the purposes of this analysis, 'acrophase' is the time of day at which peak cognitive effectiveness occurs; this is normally, in the late afternoon or early evening. Acrophase is easily disturbed by night work, shift rotation (shift lag) and time zone changes (jet-lag). In the context of this report, the acrophase shows the number of days required for adaptation to each watch schedule and whether the adaptation results in a circadian phase advance or a phase delay and the number of hours of phase change.

2.2 Modeling methods

Since the goal was to develop alternative watch schedules, the modeling methods are based on prescribed sleep timings as opposed to sleep measured by wrist actigraphs.

The daily performance nadir occurs during physiologic night. In an effort to limit exposure to night watches for any given watch syndicate, the alternative watch schedules developed at the symposium (see Annexes A - C) are structured to break up the night period (defined here as from midnight to about 0800 hours) at 0400 hours. The exact watch timings for each syndicate of each alternative watch system are described in the next paragraphs.

2.3 Description of alternative watch schedules

1-in-3 straight eights

Syndicate A works from 0400 to 1200 hours and sleeps from 1800 to 0200 hours. Syndicate B works from 1200 to 2000 hours and sleeps from 0200 to 1000 hrs. Syndicate C works from 2000 to 0400 hours and sleeps from 1000 to 1800 hours.

1-in-3 straight fours

Syndicate A works from 2400 to 0400 hours and from 1200 to 1600 hours, sleeping from 1630 to 2330 hours. Syndicate B works from 0400 to 0800 hours and from 1600 to 2000 hours, sleeping from 2030 to 0330 hours. Syndicate C works from 0800 to 1200 hours and from 2000 to 2400 hours, sleeping from 0030 to 0730 hours.

1-in-2 (8-4-4-8)

The port watch works from 0400 to 1200 hours and from 1600 to 2000 hours, sleeping from 2100 to 0300 hours. The starboard watch works from 1200 to 1600 hours and from 2000 to 0400 hours, sleeping from 0500 to 1100 hours.

1-in-2 (6-6-6-6)

The front watch works from 0700 to 1300 hours and from 1900 to 0100 hours. The back watch works from 0100 to 0700 hours and from 1300 to 1900 hours. While both front and back watches have sleep opportunities after each 6-hour work period, the models for each of these 2 watch syndicates are based on actual sleep data collected during the 2007 at-sea trial on HMCS Corner Brook (as opposed to prescribed sleep behaviour).

3 Results

The key summary statistics from all watch systems are illustrated in Table A1, Annex A. For each alternative watch system (1-in-3 straight eights, 1-in-3 straight fours, and 1-in-2 (8-4-4-8), the models, the schematic illustrations of watch and sleep times, and the performance statistics are illustrated in Annexes B - D. The models, schematic illustrations of watch and sleep times, and performance statistics for the watch system currently in use (1-in-2 (6-6-6-6)) are illustrated in Annex E.

The amount of jetlag needed to induce significant cognitive impairment is a circadian change of at least 3 hours at a rate faster than 1 hour per day. In the context of this report, one half of that limit (i.e., 1.5 hours) is used to establish the day at which the model acrophase is within 1.5 hours of its final position, meaning that the crew is relatively well adapted to the watch.

3.1 1-in-3 straight eights

Syndicate A results in a 5-hour phase delay over 7 days of adaptation to this watch schedule. During this 6-day adaptation period, the mean and minimum cognitive effectiveness levels are 89 and 86 percent, respectively (Figure B1). The work and sleep times for this syndicate are illustrated in Figure B.1.1. The summary statistics for this watch syndicate are illustrated in Table B.1.2. Over the 28-day model period, mean cognitive effectiveness is 95 percent and the percent of work time spent below the criterion line (BCL) is zero (Table A1). The criterion line is set at 77%, the cognitive performance effectiveness value that is associated with a BAC of 0.05%.

Syndicate B results in a 4-hour phase advance over 6 days of adaptation. During this 6-day adaptation period, the mean and minimum cognitive effectiveness levels are 92 and 87 percent, respectively (Table A1, and Figure B2). The work and sleep times for this syndicate are illustrated in Figure B.2.1. The summary statistics for this watch syndicate are illustrated in Table B.2.2. Over the 28-day model period, the mean cognitive effectiveness level is 96 percent and the percent of work time spent below BCL is zero (Table A1).

Syndicate C results in an 11-hour phase advance over 16 days of adaptation. During this 16-day adaptation period, the mean and minimum cognitive effectiveness are 94 and 89 percent, respectively (Table A1 and Figure B3). The work and sleep times for this syndicate are illustrated in Figure B.3.1. The summary statistics for this watch syndicate are illustrated in Table B.3.2. Over the 28-day model period, the mean cognitive effectiveness level is 96 percent and the percent of work time spent below BCL is 2% (Table A1).

3.2 1-in-3 straight fours

Syndicate A results in a 7-hour phase delay over 12 days of adaptation to this watch. During this 12-day adaptation period, the mean and minimum cognitive effectiveness levels for the 0000-to-0400-hours watch are 94% and 86%, respectively, and for the 1200-to-1600-hours watch, they are

100% and 97%, respectively (Table A1 and Figure C1). The work and sleep times for this syndicate are illustrated in Figure C.1.1. The summary statistics are illustrated in Table C.1.2 (0000-to-0400-hours watch) and Table C.1.3 (1200-to-1600-hours watch). Over the 28-day model, for the 0000-to-0400-hours watch, mean cognitive effectiveness and percent BCL are 98% and 0%, respectively, and for the 1200-to-1600-hours watch, they are 100% and 0%, respectively (Table A1).

Syndicate B results in a 3-hour phase delay over 4 days of adaptation to this watch. During the 4-day adaptation period, the mean and minimum cognitive effectiveness for the 0400-to-0800-hours watch are 90% and 89%, respectively, and for the 1600-to-2000-hours watch, they are 94% and 92%, respectively (Table A1 and Figure C2). The work and sleep times for this syndicate are illustrated in Figure C.2.1. The summary statistics are illustrated in Table C.2.2 (0400-to-0800-hours watch) and Table C.2.3 (1600-to-2000 hours watch). Over the 28-day model, for the 0400-to-0800-hours watch, the mean cognitive effectiveness levels and percent of the time spent below BCL are 94% and 0%, respectively, and for the 1600-to-2000-hours watch, they are also 94% and 0%, respectively (Table A1).

Syndicate C results in a 1-hour phase advance over 1-day of adaptation to this watch. During the 1-day adaptation period, the mean and minimum cognitive effectiveness levels for the 0800-to-1200-hours watch are 98% and 97%, respectively, and for the 2000-to-2400-hours watch, they are 94% and 94%, respectively (Table A1 and Figure C3). The work and sleep times for this syndicate are illustrated in Figure C.3.1. The summary statistics are illustrated in Table C.3.2 (0800-to-1200-hours watch) and Table C.3.3 (2000-to-2400-hours watch). Over the 28-day model, for the 0800-to-1200-hours watch, mean cognitive effectiveness level and percent BCL are 96% and 0%, respectively, and for the 2000-to-2400-hours watch, they are 94% and 0%, respectively (Table A1).

3.3 1-in-2 (8-4-4-8)

The port watch results in a 3-hour phase delay over 4 days of adaptation to this watch. During the 4-day adaptation period, mean and minimum cognitive effectiveness levels for the 0400-to-1200-hours watch, are 90% and 87%, respectively, and for the 1600-to-2000-hours watch, they are 89% and 89%, respectively (Table A1 and Figure D1). The work and sleep times for this syndicate are illustrated in Figure D1.1. The summary statistics are illustrated in Table D1.2. (0400-to-1200-hours watch) and Table D1.2. (1600-to-2000-hours watch). Over the 28-day model, for the 0400-to-1200-hours watch, the mean cognitive effectiveness level and percent of work time spent below BCL are 88% and 0%, respectively, and for the 1600-to-2000-hours watch, they are also 88% and 0%, respectively.

The starboard watch results in a 5-hour phase advance over 7 days of adaptation to this watch. During the 7-day adaptation period, the mean and minimum cognitive effectiveness levels for the 1200-to-1600-hours watch are 91% and 90%, respectively, and for the 2000-to-0400-hours watch, they are 85% and 83%, respectively (Table A1 and Figure D2). The work and sleep times for this syndicate are illustrated in Figure D.2.1. The summary statistics are illustrated in Table D.2.2. (1200-to-1600-hours watch) and Table D.2.3. (2000-to-0400-hours watch). Over the 28-day model, for the 1200-to-1600-hours watch, the mean cognitive effectiveness and percent BCL are

90% and 0%, respectively, and for the 2000-to-0400-hours watch, they are 88% and 6%, respectively.

3.4 1-in-2 (6-6-6-6, currently in use in CF submarines)

In one individual (Subject 10), the front watch did not result in any significant adaption, although the acrophase illustrates a slight phase advance of less than 1 hour over the 13-day period (Table A1 and Figure E1). The work and sleep times for this syndicate are illustrated in Figure E.1.1. The summary statistics are illustrated in Table E.1.2. (0700-to-1300-hours watch) and Table E.1.3. (1900-to-0100-hours watch). Over the 13-day model, for the 0700-to-1300-hours watch, the mean cognitive effectiveness level and percent BCL are 75% and 70%, respectively, and for the 1900-to-0001-hours watch, they are 79% and 47%, respectively (Table A1).

In another individual (Subject 04), the back watch did not result in any significant adaptation, although the acrophase illustrates a slight phase advance of less than an hour (Table A1 and Figure E2). The work and sleep times for this syndicate are illustrated in Figure E.2.1. The summary statistics are illustrated in Table E.2.2. (0100-to-0700-hours watch) and Table E.2.3. (1300-to-1900-hours watch). Over the 13-day model, for the 0100-to-0007-hours watch, the mean cognitive effectiveness level and percent BCL are 47% and 100%, respectively, and for the 1300-to-1900-hours watch, they are 63% and 81%, respectively (Table A1).

The data for Subjects 10 and 04 are from the HMCS Corner Brook at-sea trial (Paul et al. 2008). The models for these 2 subjects are based on wrist actigraphically-verified sleep.

4 Discussion

The ideal daily sleep period should be a minimum of 8 hours of uninterrupted sleep. In order to make cerebral energy (i.e., brain glycogen), the human body needs good nutrition, water, oxygen and sufficient sleep. Brain glycogen is laid down in the brain during slow wave sleep (i.e., during deep sleep) (Benington and Heller 1995). Because one cycles in and out of various sleep stages, ranging from light (Stages I and II) to deep sleep (Stages III and IV) and Rapid Eye Movement (REM) sleep, sleep must be continuous and uninterrupted.

Seemingly minor irritations like noise, temperature, and light can keep one from reaching critical sleep stages, leading to inadequate replenishment of energy stores and lack of energy for physical and mental tasks thus compromising safety critical performance and operational readiness. Essentially, without adequate sleep, the brain and nervous system and other body systems cannot function well, leading to fatigue, irritability, withdrawal, impaired thinking and a compromised ability to communicate well with others.

There is little doubt that shift work is associated with a number of health problems such as poor sleep, gastrointestinal disorders, abnormal metabolic responses and increased risk of accidents (Arendt 2010; Moore-Ede and Richardson 1985). Over the long term, shift-workers are at a higher risk of major disease such as heart disease and cancer (Stevens 2005).

In the submarine operational context, it would therefore be prudent to take any opportunity to ameliorate watch schedules with a view to improving crew sleep hygiene. Such efforts will result in improved operational readiness, improvement in quality of life (and perhaps improved recruitment and retention of submariners), and a reduction of risk for major disease.

A review of Table 1 (Annex A) will confirm that a 1-in-3 straight eights (one daily work period of 8 hours) and a 1-in-3 straight fours (two daily 4-hour work periods) watch systems can result in the best levels of crew performance. Unfortunately, only large submarines with large crews (USN and RN ballistic missile boats and USN nuclear powered attack boats) have crews large enough to opt for a 1-in-3 straight eights or straight fours watch system.

Nations that operate small diesel-powered attack boats which typically have small crews cannot employ a 1-in-3 straight eights watch system. Small diesel-powered boats are limited to a 1-in-2 watch system where they are on watch for 12 hours a day. The current CF submarine schedule dictates two 6-hour watches per day with 6 hours off between watches (for the tactical members of the crews). The 2007 at-sea trial on HMCS Corner Brook revealed alarmingly low levels of cognitive effectiveness in these tactical crew members (Paul et al. 2008). The international attendees at the recent Submarine Watch Schedule Symposium (hosted by DRDC Toronto) developed an alternative 1-in-2 watch system (8 hours on, 4 hours off, 4 hours on, 8 hours off), that can result in a significant improvement over the current watch system, although it is not as sparing of crew performance as a 1-in-3 straight eights or 1-in-3 straight fours watch systems. The proposed new 1-in-2 watch system prescribes a single 6-hour sleep duration during the 8-hour off period and is modeled on that amount of sleep. Should crew members have the opportunity to spent part of their 4-hour off period sleeping, it is expected that their performance will improve further.

The current CF watch system as trialed on HMCS Corner Brook demonstrated modeled cognitive effectiveness level ranges from 75% (0700-to-1300-hours watch) to 79% (1900-to-0100-hours watch) for the front watch, and 47% (0100-to-0700-hours watch) to 63% (1300-to-1900-hours watch) for the back watch. For the front watch, the percentage of time spent below the criterion line of 77% (i.e., performance equivalent to or worse than BAC of 0.05%) is 70% for 0700-to-1300-hours watch, and 47% for the 1900-to-0100-hours watch. The corresponding values for the back watch are 100% of the work period for the 0100-to-0700-hour watch, and 81% of the work period for the 1300-to-1900-hours watch. Within these current watches, much of the time is spent below a BAC equivalent to 0.08% or worse.

In contrast, the proposed 1-in2 (8-4-4-8) watch schedule modeled cognitive effectiveness ranges between 88% and 90% for both work periods of each of the watch syndicates (i.e., for the port and starboard watch syndicates). Generally, modeled performance does not reach the criterion line for BAC of 0.05%, except for 6% of the time during the 2000-to-0400-hours watch of the starboard syndicate.

It must be emphasized that the statistics in the preceding paragraph are for 6 hours of sleep. Should only 5 hours of sleep be realized, then the mean cognitive effectiveness level will fall to 79 - 80%. Also, during the two evening watches (2000-to-0400-hours (starboard watch), and 1600-to-2000-hours (port watch)), 30 - 32% of work time will be spent below the criterion line for a BAC of 0.05%. This point reinforces the fact that the crews should be encouraged to take every opportunity for sleep.

5 Recommendations

The proposed new 1-in-2 watch system should be trialed at-sea, with a view to adapting operational routines to that watch system. If successful, the new watch system should be systematically employed on all CF boats. While it is understood that the current 1-in-3 engineers' watch is restricted to 3- and 4-hour watches since 4 hours is the upper limit for watches in the very hot and very noisy environment of the engine room, it is also understood that not all of the on-duty engineers are in the engine room at the same time. Engineers also work in other technical spaces of the boat, and these spaces are not hot and noisy like the engine room. Therefore, if the engineers rotate between the engine room and the non-engine-room engineering spaces every 4 hours within the 2 daily 8-hour watches (one 8-hour watch for the port watch syndicate and one 8-hour watch for the starboard watch syndicate) in concert with the same watch times as the tactical watch keepers, then a single watch system could be employed boat-wide.

When the CF next acquires replacement submarines, they should consider that these should be large enough to accommodate a crew complement that will be able to undertake either 1-in-3 straight eights or 1-in-3 straight fours watch systems. The CF might want to avoid small boats like the German 212 and 214 Class with their small crew complements, since such small crews will preclude optimization of a watch schedule with the attendant fatigue-induced impact or submariner performance, and will result in a poor quality of life and higher risk of major disease in CF submariners.

In an effort to further improve sleep and circadian hygiene among submarine crews, appropriate 24/7 lighting (of optimal light energy wavelength and light intensity) could be installed in all appropriate work areas of the boat. During any wake period, when exposure to light is not appropriate, the crew could wear special eye-glasses (e.g., Zircadium™ eye-glasses developed by Professor Bob Casper and his team at the Samuel Lunenfeld Research Institute of the University of Toronto) which block out the light energy wavelengths that are responsible for suppression of melatonin. Such a protocol would certainly improve circadian hygiene, which in turn would improve performance. Glasses of this type are now becoming available, and an operational evaluation of their efficacy in long range air transport operations is being planned. The results of that trial will be relevant to submarine operations.

Up until the point where the crew is relatively well adapted to their respective watch times, in those who have difficulty sleeping it might be helpful to prescribe zopiclone (which is currently being used by CF air transport aircrews during missions that are known to impact on crew sleep hygiene) (Paul et al. 2001; Paul et al. 2003; Paul et al. 2004a; Paul et al. 2004b). In those who are unduly tired during a watch, alertness could be facilitated either by caffeinated chewing gum or modafinil, which is an alertness enhancing drug that has been shown in DRDC Toronto studies to be efficacious (Pigeau et al. 1995) and have no abuse liability, and which is approved by the US Food and Drug Administration for use by shiftworkers.

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Annex A Adaptation times, phase changes, and percent cognitive effectiveness across watch systems within each watch system

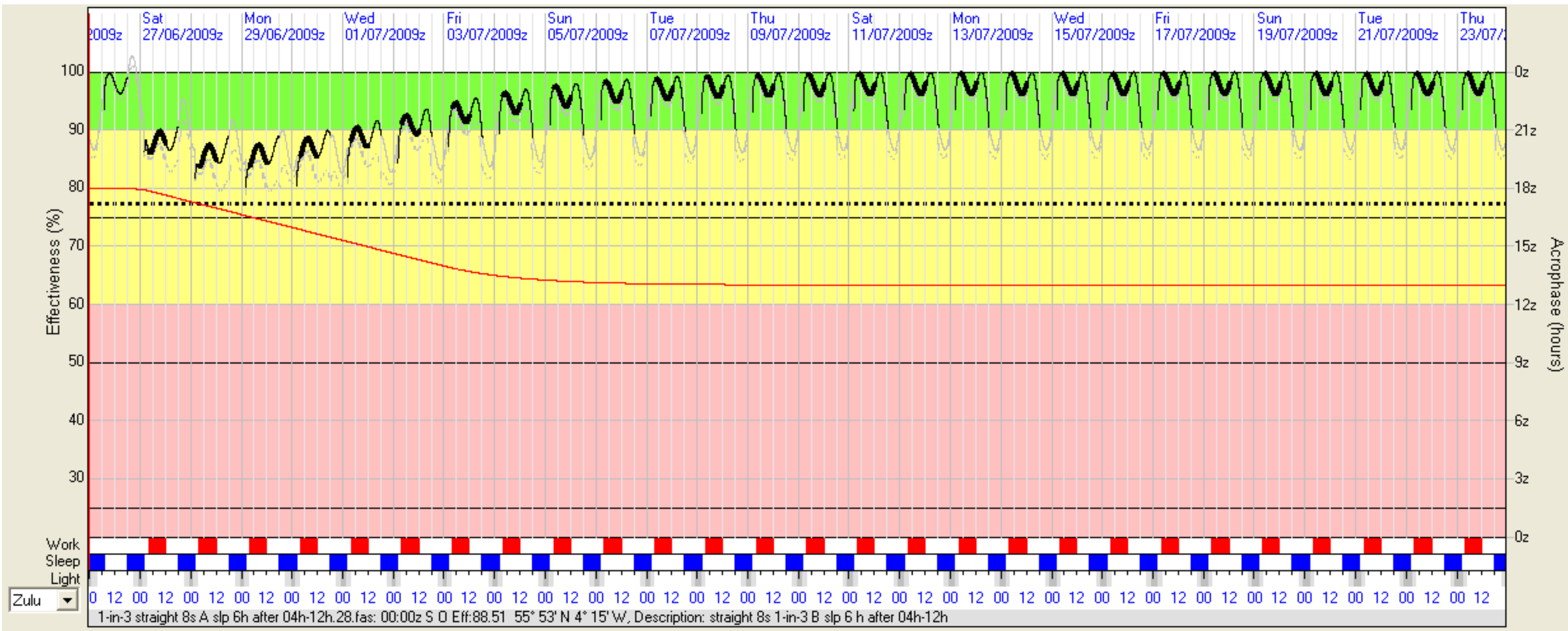
Table A1. adaptation times, phase changes, and percent cognitive effectiveness across watch systems and syndicates within each system

		Phase Change	Percent Cognitive Effectiveness			
Watch system	Adaptation time	Advance or Delay	During adaptation period		Averaged over 28 days	
1-in-3 Straight 8s			mean	minimum	mean	* % BCL
A syndicate (04-12 h)	7 days	5 hour delay	89	86	95	0
B syndicate (12-20h)	6 days	4 hour advance	92	87	96	0
C syndicate (20-04h)	16 days	11 hour advance	94	89	96	2
1-in-3 Straight 4s						
A synd (00-04 & 12-16h)	12 days	7 hour delay	*** 94/100	86/97	98/100	0/0
B synd (04-08 & 16-20 h)	4 days	3 hour delay	*** 90/94	89/92	94/94	0/0
C synd (08-12 & 20-24 h)	1 day	1 hour advance	*** 98/94	97/94	96/94	0/0
1-in-2 (8-4-4-8)						
Port synd (04-12 & 16-20 h)	4 days	3.0 hour delay	*** 90/89	87/89	88/88	0/0
Stbd synd (12-16 & 20-04 h)	7 days	5 hour advance	*** 91/85	90/83	90/88	0/6
** 1-in-2 (6-6-6-6)						
Front synd (07-13 & 19-01 h)	No adaptation	<1 hour advance			*** 75/79	70/47
Back synd (01-07 & 13-19 h)	No adaptation	< 1 hour advance			*** 47/63	100/81

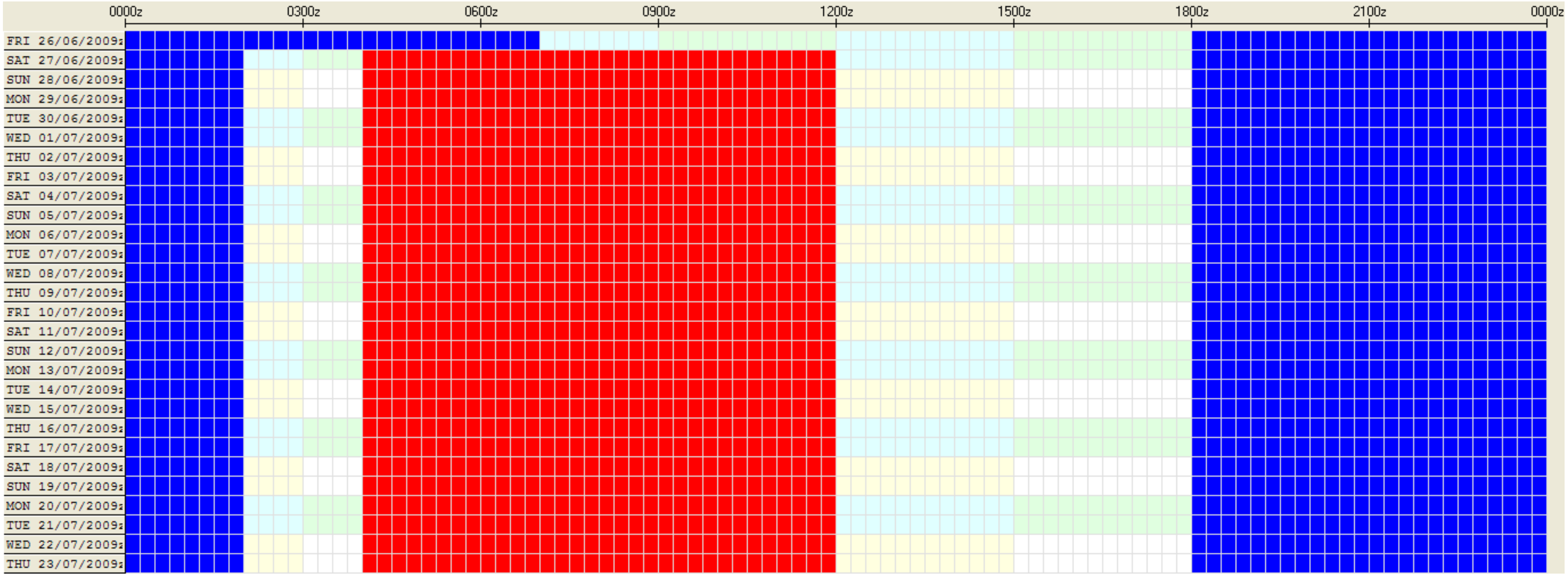
* % BCL = percent below criterion line of 77% cognitive effectiveness or worse than Blood alcohol equivalent of 0.05%
** 13-day models where sleep was measured via actigraph during 2007 Corner Brook at-sea trial
*** values for first/second work periods of the watch

Annex B 1-in-3 Straight eights watch system

B.1 Figure B1. Syndicate A, work from 04:00 to 12:00 h and sleep from 18:00 to 02:00 h



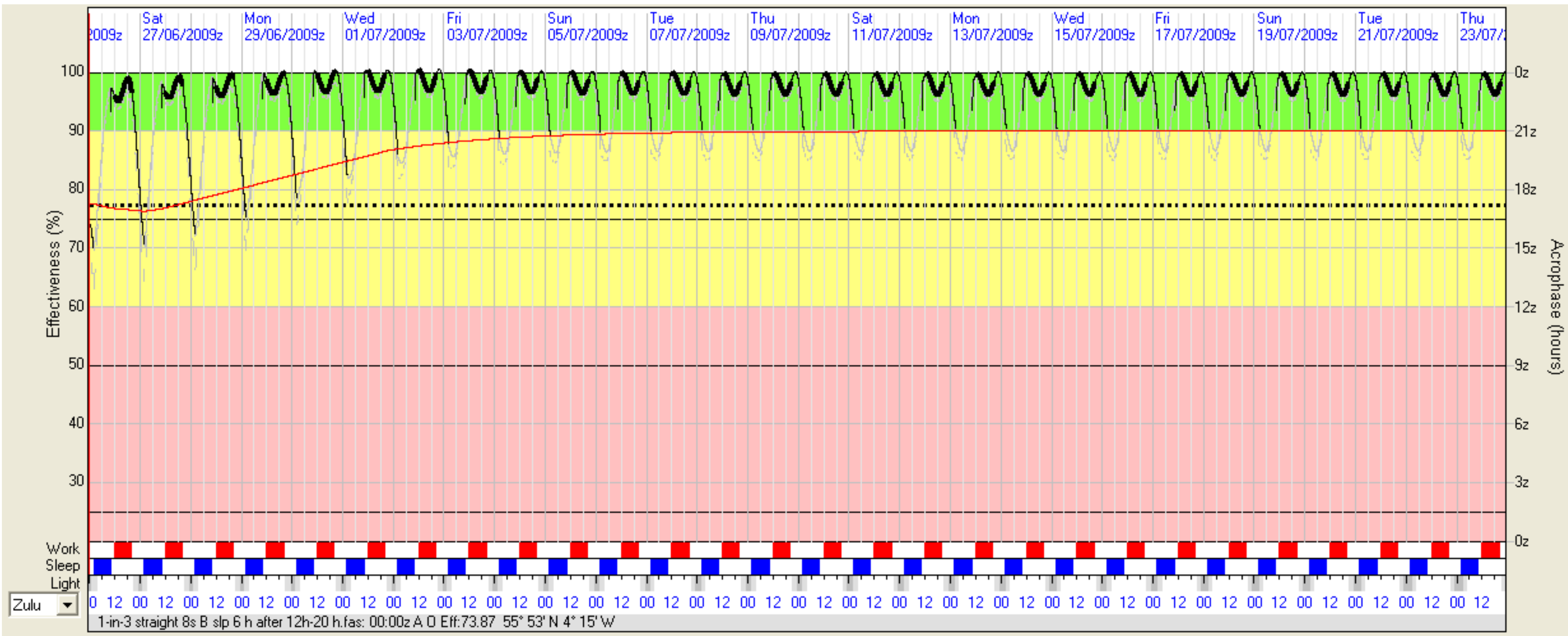
B.1.1 Figure B.1.1. Syndicate A sleep (blue) and work (red) periods



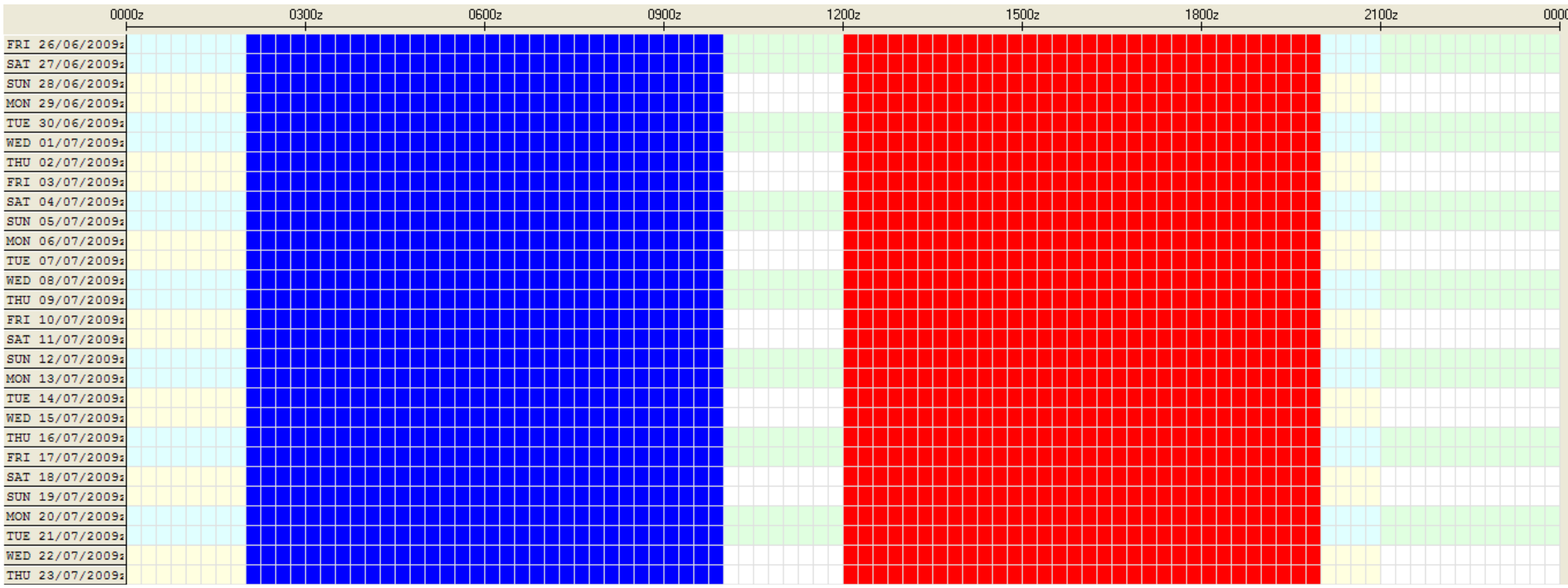
B.1.2 Table B1.2. Syndicate A work period statistics

1-in-3 straight 8s Syndicate A								
Start		start work			end work	Stats		
Day	Date	Time	Day	Date	Time	Dur	Eff	%BCL
Sat	27/06/2009z	04:00z	Satz	27/06/2009z	12:00z	480	88.19	0
Sun	28/06/2009z	04:00z	Sunz	28/06/2009z	12:00z	480	85.99	0
Mon	29/06/2009z	04:00z	Monz	29/06/2009z	12:00z	480	86.03	0
Tue	30/06/2009z	04:00z	Tuez	30/06/2009z	12:00z	480	87.2	0
Wed	01/07/2009z	04:00z	Wedz	01/07/2009z	12:00z	480	88.96	0
Thu	02/07/2009z	04:00z	Thuz	02/07/2009z	12:00z	480	90.97	0
Fri	03/07/2009z	04:00z	Friz	03/07/2009z	12:00z	480	92.97	0
Sat	04/07/2009z	04:00z	Satz	04/07/2009z	12:00z	480	94.54	0
Sun	05/07/2009z	04:00z	Sunz	05/07/2009z	12:00z	480	95.62	0
Mon	06/07/2009z	04:00z	Monz	06/07/2009z	12:00z	480	96.36	0
Tue	07/07/2009z	04:00z	Tuez	07/07/2009z	12:00z	480	96.86	0
Wed	08/07/2009z	04:00z	Wedz	08/07/2009z	12:00z	480	97.19	0
Thu	09/07/2009z	04:00z	Thuz	09/07/2009z	12:00z	480	97.41	0
Fri	10/07/2009z	04:00z	Friz	10/07/2009z	12:00z	480	97.55	0
Sat	11/07/2009z	04:00z	Satz	11/07/2009z	12:00z	480	97.64	0
Sun	12/07/2009z	04:00z	Sunz	12/07/2009z	12:00z	480	97.7	0
Mon	13/07/2009z	04:00z	Monz	13/07/2009z	12:00z	480	97.73	0
Tue	14/07/2009z	04:00z	Tuez	14/07/2009z	12:00z	480	97.73	0
Wed	15/07/2009z	04:00z	Wedz	15/07/2009z	12:00z	480	97.74	0
Thu	16/07/2009z	04:00z	Thuz	16/07/2009z	12:00z	480	97.74	0
Fri	17/07/2009z	04:00z	Friz	17/07/2009z	12:00z	480	97.74	0
Sat	18/07/2009z	04:00z	Satz	18/07/2009z	12:00z	480	97.74	0
Sun	19/07/2009z	04:00z	Sunz	19/07/2009z	12:00z	480	97.74	0
Mon	20/07/2009z	04:00z	Monz	20/07/2009z	12:00z	480	97.74	0
Tue	21/07/2009z	04:00z	Tuez	21/07/2009z	12:00z	480	97.74	0
Wed	22/07/2009z	04:00z	Wedz	22/07/2009z	12:00z	480	97.74	0
Thu	23/07/2009z	04:00z	Thuz	23/07/2009z	12:00z	480	97.74	0
means						480	95.05	0

B.2 Figure B2. Syndicate B, work from 12:00 to 20:00 h and sleep from 02:00 to 10:00 h



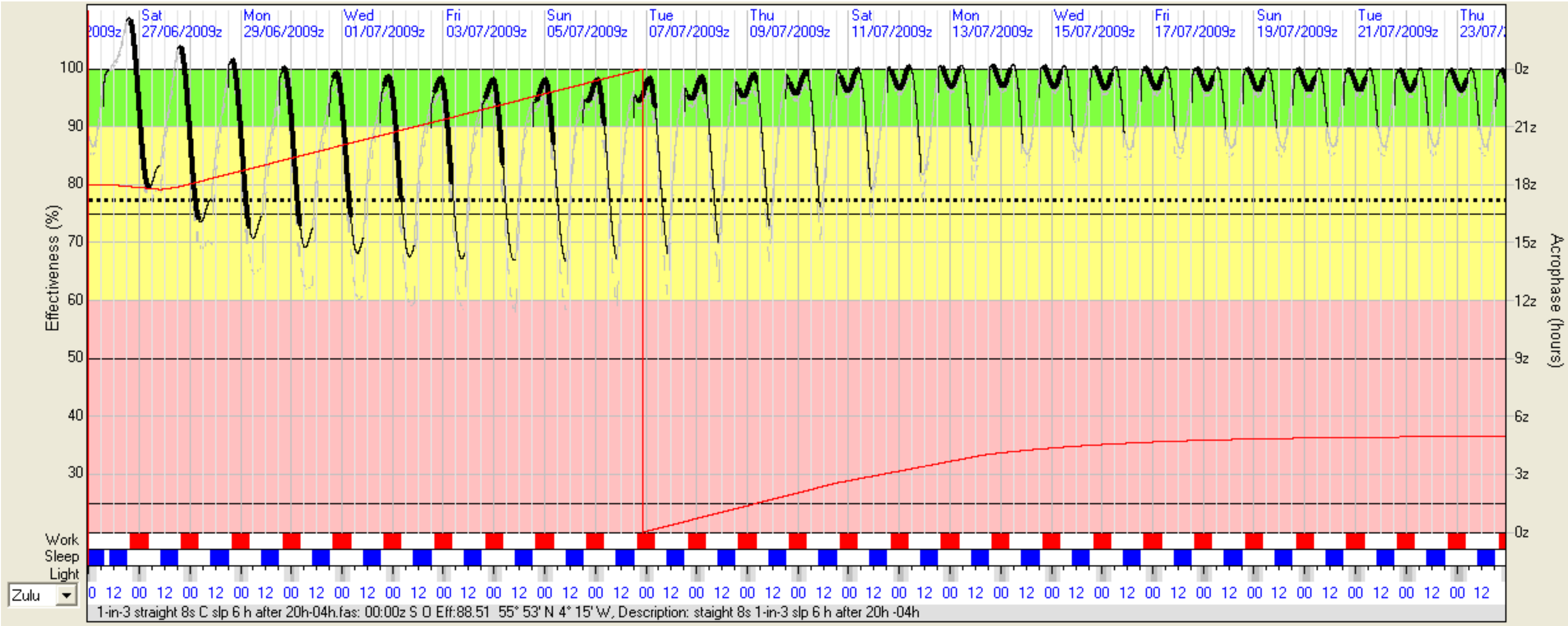
B.2.1 Figure B.2.1. Syndicate B sleep (blue) and work (red) periods



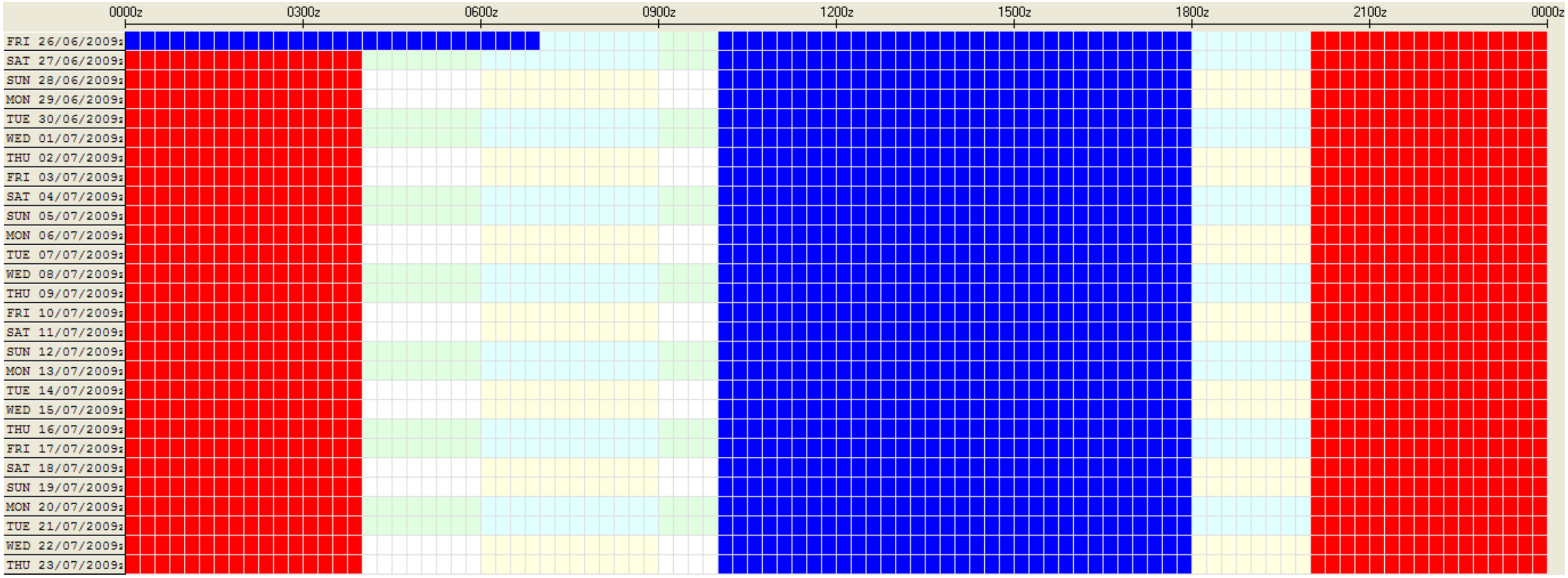
B.2.2 Table B.2.2. Syndicate B work period statistics

1-in-3 straight 8s B								
Start		start work			end work		Stats	
Day	Date	Time	Day	Date	Time	Dur	Eff	%BCL
Fri	26/06/2009z	06:00z	Friz	26/06/2009z	14:00z	480	87.27	0
Sat	27/06/2009z	06:00z	Satz	27/06/2009z	14:00z	480	89.52	0
Sun	28/06/2009z	06:00z	Sunz	28/06/2009z	14:00z	480	91.5	0
Mon	29/06/2009z	06:00z	Monz	29/06/2009z	14:00z	480	93.39	0
Tue	30/06/2009z	06:00z	Tuez	30/06/2009z	14:00z	480	94.82	0
Wed	01/07/2009z	06:00z	Wedz	01/07/2009z	14:00z	480	95.82	0
Thu	02/07/2009z	06:00z	Thuz	02/07/2009z	14:00z	480	96.49	0
Fri	03/07/2009z	06:00z	Friz	03/07/2009z	14:00z	480	96.94	0
Sat	04/07/2009z	06:00z	Satz	04/07/2009z	14:00z	480	97.24	0
Sun	05/07/2009z	06:00z	Sunz	05/07/2009z	14:00z	480	97.44	0
Mon	06/07/2009z	06:00z	Monz	06/07/2009z	14:00z	480	97.57	0
Tue	07/07/2009z	06:00z	Tuez	07/07/2009z	14:00z	480	97.66	0
Wed	08/07/2009z	06:00z	Wedz	08/07/2009z	14:00z	480	97.71	0
Thu	09/07/2009z	06:00z	Thuz	09/07/2009z	14:00z	480	97.73	0
Fri	10/07/2009z	06:00z	Friz	10/07/2009z	14:00z	480	97.74	0
Sat	11/07/2009z	06:00z	Satz	11/07/2009z	14:00z	480	97.74	0
Sun	12/07/2009z	06:00z	Sunz	12/07/2009z	14:00z	480	97.74	0
Mon	13/07/2009z	06:00z	Monz	13/07/2009z	14:00z	480	97.74	0
Tue	14/07/2009z	06:00z	Tuez	14/07/2009z	14:00z	480	97.74	0
Wed	15/07/2009z	06:00z	Wedz	15/07/2009z	14:00z	480	97.74	0
Thu	16/07/2009z	06:00z	Thuz	16/07/2009z	14:00z	480	97.74	0
Fri	17/07/2009z	06:00z	Friz	17/07/2009z	14:00z	480	97.74	0
Sat	18/07/2009z	06:00z	Satz	18/07/2009z	14:00z	480	97.74	0
Sun	19/07/2009z	06:00z	Sunz	19/07/2009z	14:00z	480	97.74	0
Mon	20/07/2009z	06:00z	Monz	20/07/2009z	14:00z	480	97.74	0
Tue	21/07/2009z	06:00z	Tuez	21/07/2009z	14:00z	480	97.74	0
Wed	22/07/2009z	06:00z	Wedz	22/07/2009z	14:00z	480	97.74	0
Thu	23/07/2009z	06:00z	Thuz	23/07/2009z	14:00z	480	97.74	0
means						480	96.41	0

B.3 Figure B3. Syndicate C, work from 20:00 to 04:00 h and sleep from 10:00 to 18:00 h



B.3.1 Figure B.3.1. Syndicate C sleep (blue) and work (red) periods



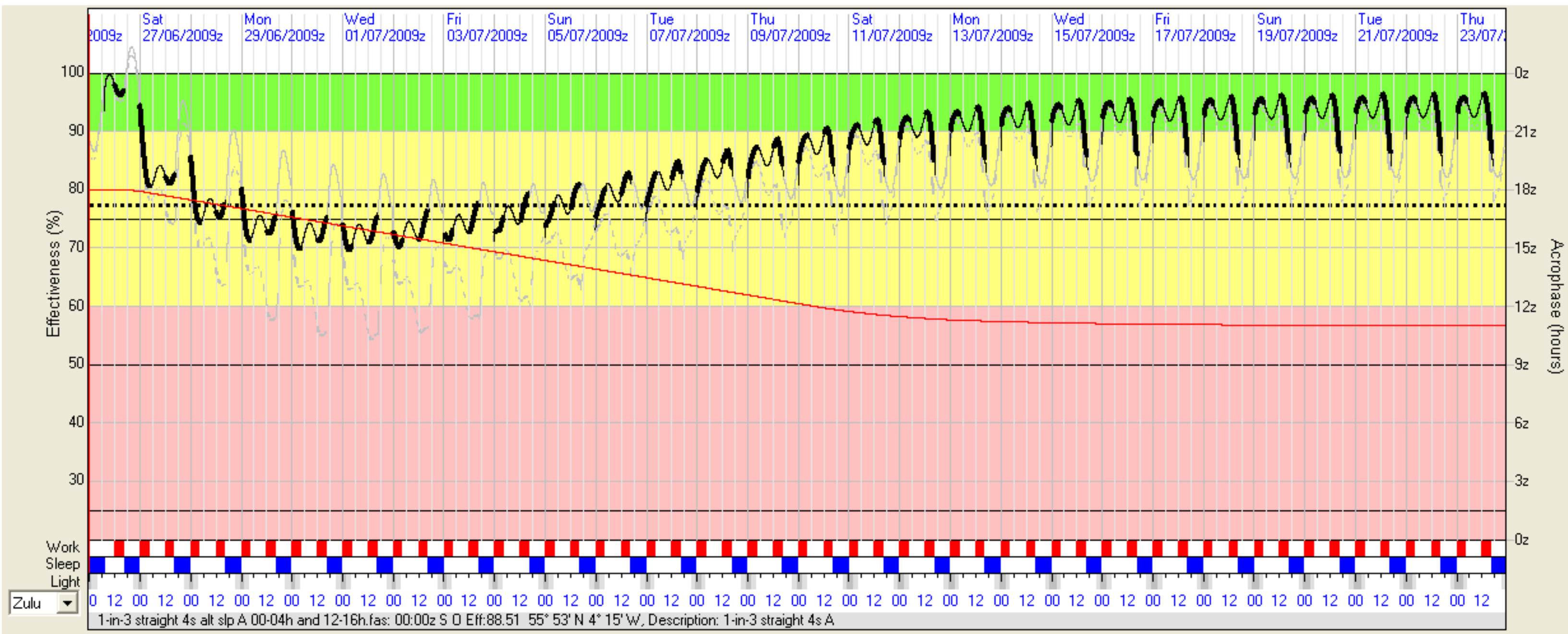
B.3.2 Table B.3.2. Syndicate C work period statistics

1-in-3 straight 8s C

Start		start work		end work			stats	
Day	Date	Time	Day	Date	Time	Dur	Eff	%BCL
Fri	26/06/2009z	20:00z	Satz	27/06/2009z	04:00z	480	93.8	0
Sat	27/06/2009z	20:00z	Sunz	28/06/2009z	04:00z	480	89.12	17.29
Sun	28/06/2009z	20:00z	Monz	29/06/2009z	04:00z	480	88.98	17.92
Mon	29/06/2009z	20:00z	Tuez	30/06/2009z	04:00z	480	89.89	13.96
Tue	30/06/2009z	20:00z	Wedz	01/07/2009z	04:00z	480	91.19	7.92
Wed	01/07/2009z	20:00z	Thuz	02/07/2009z	04:00z	480	92.54	0.83
Thu	02/07/2009z	20:00z	Friz	03/07/2009z	04:00z	480	93.74	0
Fri	03/07/2009z	20:00z	Satz	04/07/2009z	04:00z	480	94.7	0
Sat	04/07/2009z	20:00z	Sunz	05/07/2009z	04:00z	480	95.43	0
Sun	05/07/2009z	20:00z	Monz	06/07/2009z	04:00z	480	95.97	0
Mon	06/07/2009z	20:00z	Tuez	07/07/2009z	04:00z	480	96.37	0
Tue	07/07/2009z	20:00z	Wedz	08/07/2009z	04:00z	480	96.7	0
Wed	08/07/2009z	20:00z	Thuz	09/07/2009z	04:00z	480	97.01	0
Thu	09/07/2009z	20:00z	Friz	10/07/2009z	04:00z	480	97.34	0
Fri	10/07/2009z	20:00z	Satz	11/07/2009z	04:00z	480	97.72	0
Sat	11/07/2009z	20:00z	Sunz	12/07/2009z	04:00z	480	98.08	0
Sun	12/07/2009z	20:00z	Monz	13/07/2009z	04:00z	480	98.3	0
Mon	13/07/2009z	20:00z	Tuez	14/07/2009z	04:00z	480	98.41	0
Tue	14/07/2009z	20:00z	Wedz	15/07/2009z	04:00z	480	98.31	0
Wed	15/07/2009z	20:00z	Thuz	16/07/2009z	04:00z	480	98.14	0
Thu	16/07/2009z	20:00z	Friz	17/07/2009z	04:00z	480	98.03	0
Fri	17/07/2009z	20:00z	Satz	18/07/2009z	04:00z	480	97.94	0
Sat	18/07/2009z	20:00z	Sunz	19/07/2009z	04:00z	480	97.88	0
Sun	19/07/2009z	20:00z	Monz	20/07/2009z	04:00z	480	97.84	0
Mon	20/07/2009z	20:00z	Tuez	21/07/2009z	04:00z	480	97.81	0
Tue	21/07/2009z	20:00z	Wedz	22/07/2009z	04:00z	480	97.79	0
Wed	22/07/2009z	20:00z	Thuz	23/07/2009z	04:00z	480	97.78	0
means						480	95.81	2.15

Annex C 1-in-3 Straight fours watch system

C.1 Figure C1. Syndicate A, work from 00:00 to 04:00 h plus 12:00 to 16:00 n with sleep from 16:30 to 23:30 h



C.1.1 Syndicate A sleep (blue) and work (red) periods

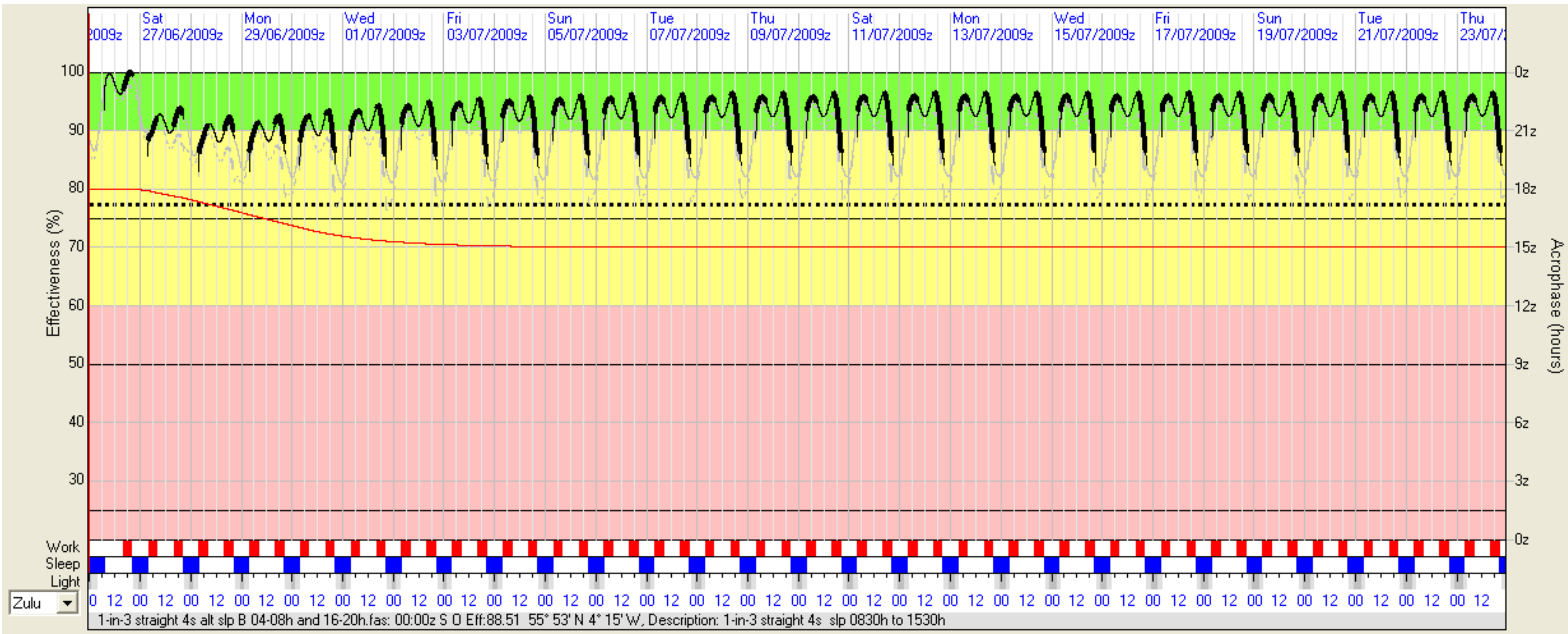
C.1.2 Table C.1.2. Syndicate A work period statistics for 00:00 to 04:00 h watch

1-in-3 straight 4s								
Start		start work			end work		Stats	
Day	Date	Time	Day	Date	Time	Dur	Eff	%BCL
Sat	27/06/2009z	00:00z	Satz	27/06/2009z	04:00z	240	86.21	0
Sun	28/06/2009z	00:00z	Sunz	28/06/2009z	04:00z	240	87.97	0
Mon	29/06/2009z	00:00z	Monz	29/06/2009z	04:00z	240	90.07	0
Tue	30/06/2009z	00:00z	Tuez	30/06/2009z	04:00z	240	91.81	0
Wed	01/07/2009z	00:00z	Wedz	01/07/2009z	04:00z	240	93.24	0
Thu	02/07/2009z	00:00z	Thuz	02/07/2009z	04:00z	240	94.42	0
Fri	03/07/2009z	00:00z	Friz	03/07/2009z	04:00z	240	95.33	0
Sat	04/07/2009z	00:00z	Satz	04/07/2009z	04:00z	240	96.05	0
Sun	05/07/2009z	00:00z	Sunz	05/07/2009z	04:00z	240	96.63	0
Mon	06/07/2009z	00:00z	Monz	06/07/2009z	04:00z	240	97.13	0
Tue	07/07/2009z	00:00z	Tuez	07/07/2009z	04:00z	240	97.57	0
Wed	08/07/2009z	00:00z	Wedz	08/07/2009z	04:00z	240	98.02	0
Thu	09/07/2009z	00:00z	Thuz	09/07/2009z	04:00z	240	98.46	0
Fri	10/07/2009z	00:00z	Friz	10/07/2009z	04:00z	240	98.9	0
Sat	11/07/2009z	00:00z	Satz	11/07/2009z	04:00z	240	99.33	0
Sun	12/07/2009z	00:00z	Sunz	12/07/2009z	04:00z	240	99.76	0
Mon	13/07/2009z	00:00z	Monz	13/07/2009z	04:00z	240	100.23	0
Tue	14/07/2009z	00:00z	Tuez	14/07/2009z	04:00z	240	100.54	0
Wed	15/07/2009z	00:00z	Wedz	15/07/2009z	04:00z	240	100.86	0
Thu	16/07/2009z	00:00z	Thuz	16/07/2009z	04:00z	240	101.16	0
Fri	17/07/2009z	00:00z	Friz	17/07/2009z	04:00z	240	101.47	0
Sat	18/07/2009z	00:00z	Satz	18/07/2009z	04:00z	240	101.76	0
Sun	19/07/2009z	00:00z	Sunz	19/07/2009z	04:00z	240	102.06	0
Mon	20/07/2009z	00:00z	Monz	20/07/2009z	04:00z	240	102.33	0
Tue	21/07/2009z	00:00z	Tuez	21/07/2009z	04:00z	240	102.6	0
Wed	22/07/2009z	00:00z	Wedz	22/07/2009z	04:00z	240	102.86	0
Thu	23/07/2009z	00:00z	Thuz	23/07/2009z	04:00z	240	103.12	0
means						240	97.8	0.0

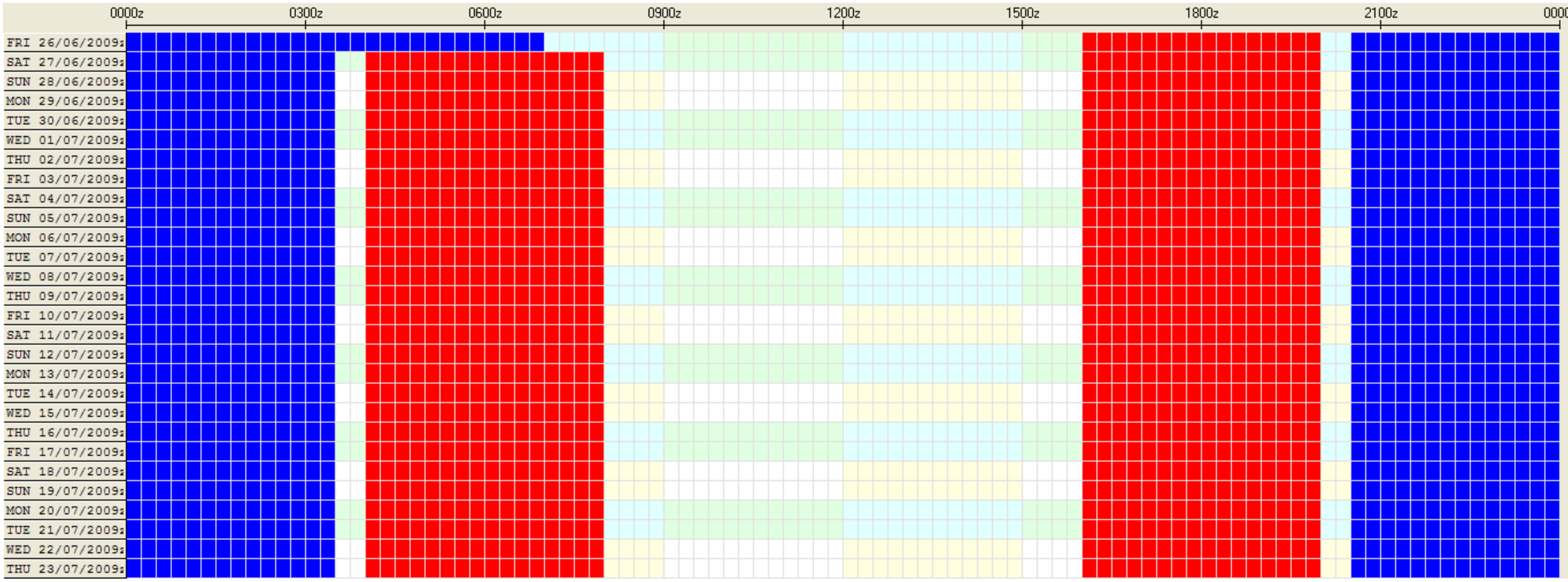
C.1.3 Table C.1.3. Syndicate A work period statistics for 12:00 to 16:00 h watch

1-in-3 straight 4s								
Start		start work			end work		Stats	
Day	Date	Time	Day	Date	Time	Dur	Eff	%BCL
Fri	26/06/2009z	12:00z	Friz	26/06/2009z	16:00z	240	96.72	0
Sat	27/06/2009z	12:00z	Satz	27/06/2009z	16:00z	240	98.54	0
Sun	28/06/2009z	12:00z	Sunz	28/06/2009z	16:00z	240	99.35	0
Mon	29/06/2009z	12:00z	Monz	29/06/2009z	16:00z	240	99.86	0
Tue	30/06/2009z	12:00z	Tuez	30/06/2009z	16:00z	240	100.25	0
Wed	01/07/2009z	12:00z	Wedz	01/07/2009z	16:00z	240	100.54	0
Thu	02/07/2009z	12:00z	Thuz	02/07/2009z	16:00z	240	100.59	0
Fri	03/07/2009z	12:00z	Friz	03/07/2009z	16:00z	240	100.53	0
Sat	04/07/2009z	12:00z	Satz	04/07/2009z	16:00z	240	100.49	0
Sun	05/07/2009z	12:00z	Sunz	05/07/2009z	16:00z	240	100.45	0
Mon	06/07/2009z	12:00z	Monz	06/07/2009z	16:00z	240	100.41	0
Tue	07/07/2009z	12:00z	Tuez	07/07/2009z	16:00z	240	100.38	0
Wed	08/07/2009z	12:00z	Wedz	08/07/2009z	16:00z	240	100.33	0
Thu	09/07/2009z	12:00z	Thuz	09/07/2009z	16:00z	240	100.29	0
Fri	10/07/2009z	12:00z	Friz	10/07/2009z	16:00z	240	100.24	0
Sat	11/07/2009z	12:00z	Satz	11/07/2009z	16:00z	240	100.18	0
Sun	12/07/2009z	12:00z	Sunz	12/07/2009z	16:00z	240	100.13	0
Mon	13/07/2009z	12:00z	Monz	13/07/2009z	16:00z	240	100.08	0
Tue	14/07/2009z	12:00z	Tuez	14/07/2009z	16:00z	240	100.03	0
Wed	15/07/2009z	12:00z	Wedz	15/07/2009z	16:00z	240	99.97	0
Thu	16/07/2009z	12:00z	Thuz	16/07/2009z	16:00z	240	99.91	0
Fri	17/07/2009z	12:00z	Friz	17/07/2009z	16:00z	240	99.85	0
Sat	18/07/2009z	12:00z	Satz	18/07/2009z	16:00z	240	99.79	0
Sun	19/07/2009z	12:00z	Sunz	19/07/2009z	16:00z	240	99.73	0
Mon	20/07/2009z	12:00z	Monz	20/07/2009z	16:00z	240	99.66	0
Tue	21/07/2009z	12:00z	Tuez	21/07/2009z	16:00z	240	99.58	0
Wed	22/07/2009z	12:00z	Wedz	22/07/2009z	16:00z	240	99.51	0
Thu	23/07/2009z	12:00z	Thuz	23/07/2009z	16:00z	240	99.43	0
means						240	99.9	0.0

C.2 Figure C2. Syndicate B, work from 04:00 to 08:00 h plus 16:00 to 20:00 n with sleep from 20:30 to 03:30 h



C.2.1 Figure C.2.1. Syndicate B sleep (blue) and work (red) periods



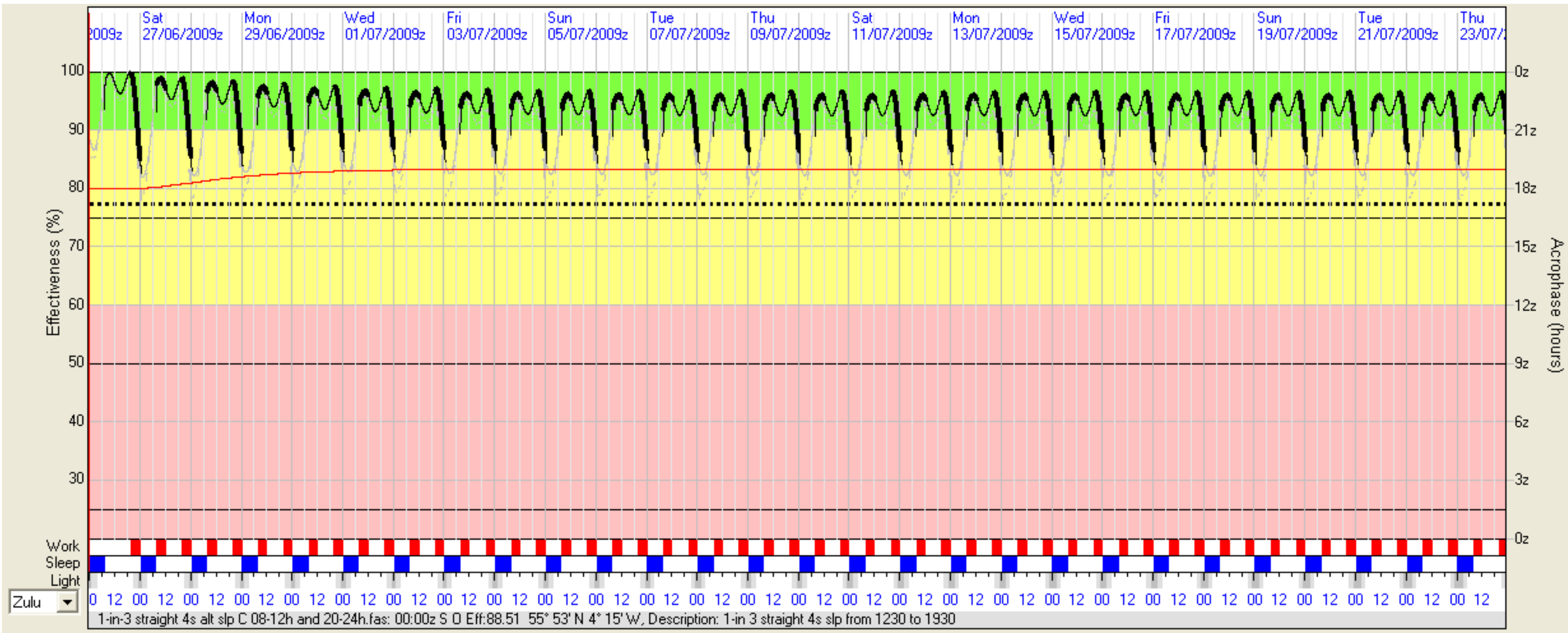
C.2.2 Table C.2.2. Syndicate B work period statistics for 04:00 to 08:00 h watch

1-in-3 straight 4s Syndicate B								
Start		work start			work end		Stats	
Day	Date	Time	Day	Date	Time	Dur	Eff	%BCL
Sat	27/06/2009z	04:00z	Satz	27/06/2009z	08:00z	240	90.33	0
Sun	28/06/2009z	04:00z	Sunz	28/06/2009z	08:00z	240	88.99	0
Mon	29/06/2009z	04:00z	Monz	29/06/2009z	08:00z	240	89.76	0
Tue	30/06/2009z	04:00z	Tuez	30/06/2009z	08:00z	240	91.31	0
Wed	01/07/2009z	04:00z	Wedz	01/07/2009z	08:00z	240	92.68	0
Thu	02/07/2009z	04:00z	Thuz	02/07/2009z	08:00z	240	93.57	0
Fri	03/07/2009z	04:00z	Friz	03/07/2009z	08:00z	240	94.16	0
Sat	04/07/2009z	04:00z	Satz	04/07/2009z	08:00z	240	94.56	0
Sun	05/07/2009z	04:00z	Sunz	05/07/2009z	08:00z	240	94.84	0
Mon	06/07/2009z	04:00z	Monz	06/07/2009z	08:00z	240	95.02	0
Tue	07/07/2009z	04:00z	Tuez	07/07/2009z	08:00z	240	95.15	0
Wed	08/07/2009z	04:00z	Wedz	08/07/2009z	08:00z	240	95.24	0
Thu	09/07/2009z	04:00z	Thuz	09/07/2009z	08:00z	240	95.3	0
Fri	10/07/2009z	04:00z	Friz	10/07/2009z	08:00z	240	95.34	0
Sat	11/07/2009z	04:00z	Satz	11/07/2009z	08:00z	240	95.36	0
Sun	12/07/2009z	04:00z	Sunz	12/07/2009z	08:00z	240	95.38	0
Mon	13/07/2009z	04:00z	Monz	13/07/2009z	08:00z	240	95.39	0
Tue	14/07/2009z	04:00z	Tuez	14/07/2009z	08:00z	240	95.4	0
Wed	15/07/2009z	04:00z	Wedz	15/07/2009z	08:00z	240	95.41	0
Thu	16/07/2009z	04:00z	Thuz	16/07/2009z	08:00z	240	95.41	0
Fri	17/07/2009z	04:00z	Friz	17/07/2009z	08:00z	240	95.41	0
Sat	18/07/2009z	04:00z	Satz	18/07/2009z	08:00z	240	95.42	0
Sun	19/07/2009z	04:00z	Sunz	19/07/2009z	08:00z	240	95.42	0
Mon	20/07/2009z	04:00z	Monz	20/07/2009z	08:00z	240	95.42	0
Tue	21/07/2009z	04:00z	Tuez	21/07/2009z	08:00z	240	95.42	0
Wed	22/07/2009z	04:00z	Wedz	22/07/2009z	08:00z	240	95.42	0
Thu	23/07/2009z	04:00z	Thuz	23/07/2009z	08:00z	240	95.42	0
means						240	94.3	0.0

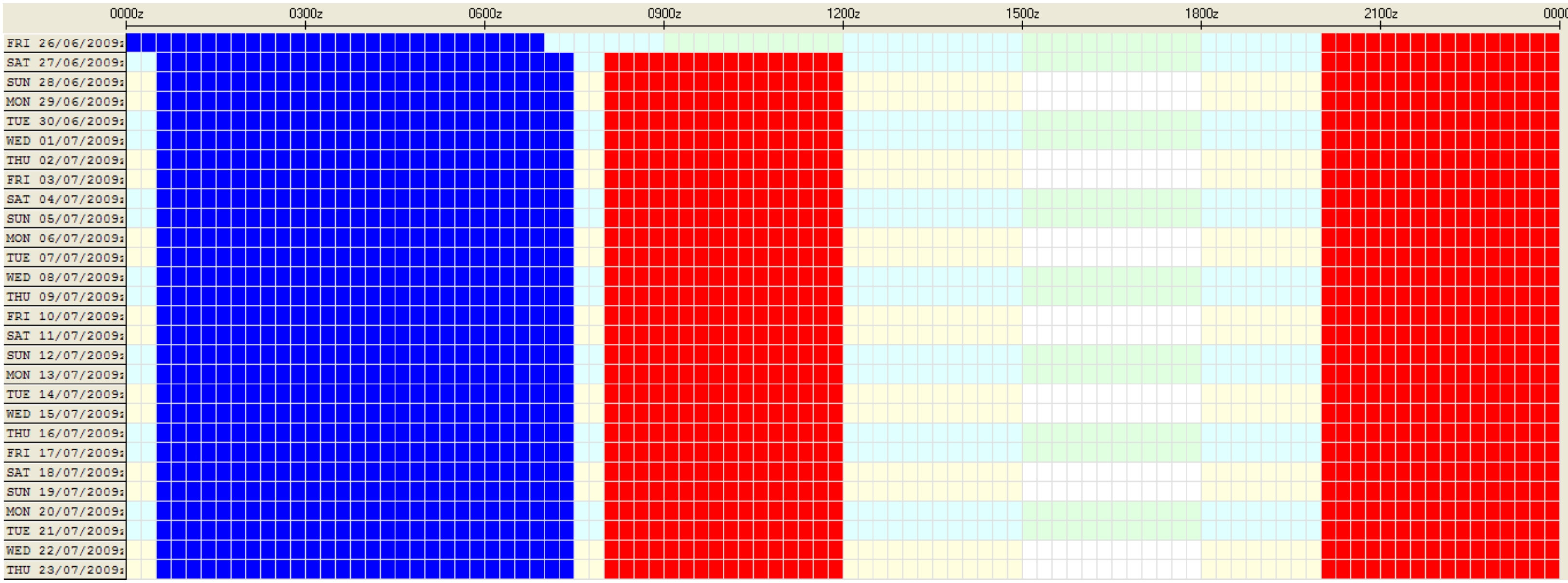
C.2.3 Table C.2.3. Syndicate B work period statistics for 16:00 to 20:00 h watch

1-in-3 straight 4s B								
Start		work start			work end		Stats	
Day	Date	Time	Day	Date	Time	Dur	Eff	%BCL
Fri	26/06/2009z	16:00z	Friz	26/06/2009z	20:00z	240	98.99	0
Sat	27/06/2009z	16:00z	Satz	27/06/2009z	20:00z	240	92.94	0
Sun	28/06/2009z	16:00z	Sunz	28/06/2009z	20:00z	240	91.59	0
Mon	29/06/2009z	16:00z	Monz	29/06/2009z	20:00z	240	91.5	0
Tue	30/06/2009z	16:00z	Tuez	30/06/2009z	20:00z	240	91.67	0
Wed	01/07/2009z	16:00z	Wedz	01/07/2009z	20:00z	240	91.94	0
Thu	02/07/2009z	16:00z	Thuz	02/07/2009z	20:00z	240	92.23	0
Fri	03/07/2009z	16:00z	Friz	03/07/2009z	20:00z	240	92.5	0
Sat	04/07/2009z	16:00z	Satz	04/07/2009z	20:00z	240	92.72	0
Sun	05/07/2009z	16:00z	Sunz	05/07/2009z	20:00z	240	92.9	0
Mon	06/07/2009z	16:00z	Monz	06/07/2009z	20:00z	240	93.04	0
Tue	07/07/2009z	16:00z	Tuez	07/07/2009z	20:00z	240	93.14	0
Wed	08/07/2009z	16:00z	Wedz	08/07/2009z	20:00z	240	93.21	0
Thu	09/07/2009z	16:00z	Thuz	09/07/2009z	20:00z	240	93.26	0
Fri	10/07/2009z	16:00z	Friz	10/07/2009z	20:00z	240	93.29	0
Sat	11/07/2009z	16:00z	Satz	11/07/2009z	20:00z	240	93.32	0
Sun	12/07/2009z	16:00z	Sunz	12/07/2009z	20:00z	240	93.33	0
Mon	13/07/2009z	16:00z	Monz	13/07/2009z	20:00z	240	93.34	0
Tue	14/07/2009z	16:00z	Tuez	14/07/2009z	20:00z	240	93.35	0
Wed	15/07/2009z	16:00z	Wedz	15/07/2009z	20:00z	240	93.36	0
Thu	16/07/2009z	16:00z	Thuz	16/07/2009z	20:00z	240	93.36	0
Fri	17/07/2009z	16:00z	Friz	17/07/2009z	20:00z	240	93.36	0
Sat	18/07/2009z	16:00z	Satz	18/07/2009z	20:00z	240	93.37	0
Sun	19/07/2009z	16:00z	Sunz	19/07/2009z	20:00z	240	93.37	0
Mon	20/07/2009z	16:00z	Monz	20/07/2009z	20:00z	240	93.37	0
Tue	21/07/2009z	16:00z	Tuez	21/07/2009z	20:00z	240	93.37	0
Wed	22/07/2009z	16:00z	Wedz	22/07/2009z	20:00z	240	93.37	0
Thu	23/07/2009z	16:00z	Thuz	23/07/2009z	20:00z	240	93.37	0
means						240	93.2	0.0

C.3 Figure C3. Syndicate C, work from 08:00 to 12:00 h plus 20:00 to 24:00 h with sleep from 00:30 to 07:30 h



C.3.1 Figure C.3.1. Syndicate C sleep (blue) and work (red) periods



C.3.2 Table C.3.2. Syndicate C work period statistics for 08:00 to 12:00 h watch

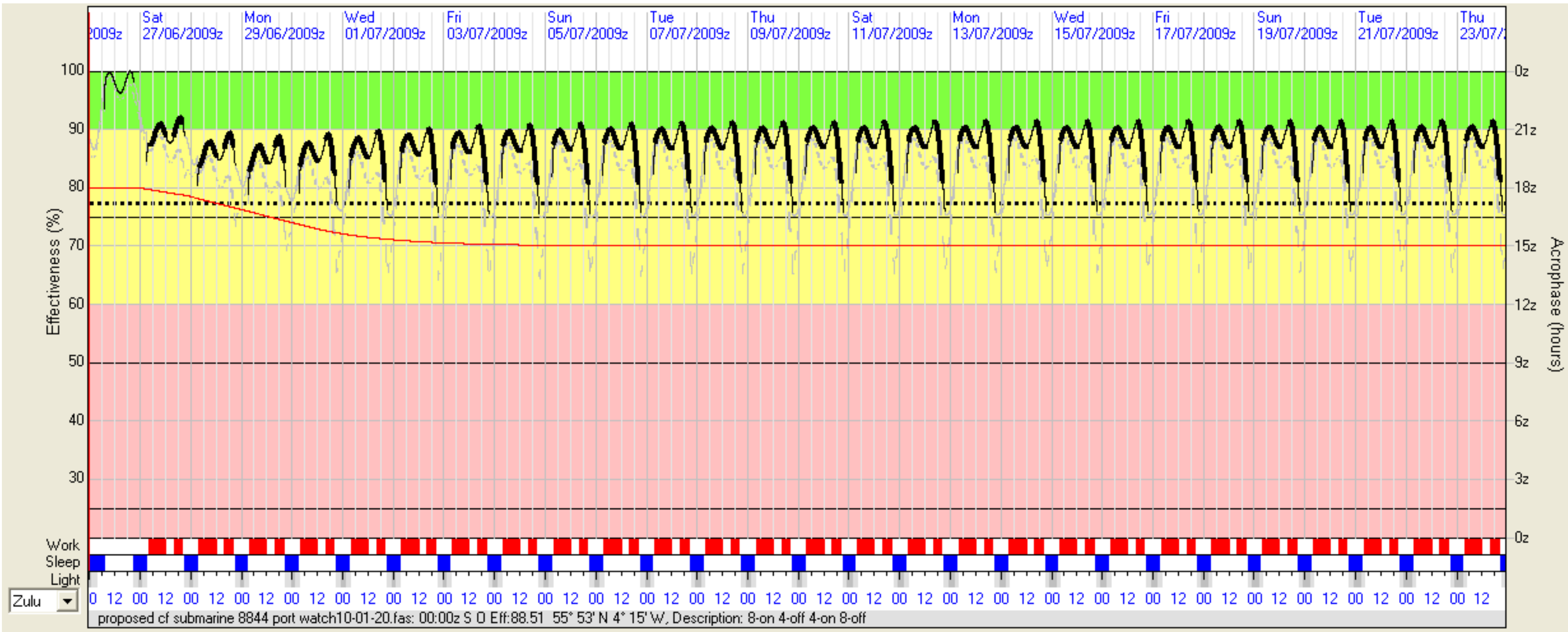
1-in-3 straight 4s C								
Start		work start			work end		Stats	
Day	Date	Time	Day	Date	Time	Dur	Eff	%BCL
Sat	27/06/2009z	08:00z	Satz	27/06/2009z	12:00z	240	98.37	0
Sun	28/06/2009z	08:00z	Sunz	28/06/2009z	12:00z	240	97.65	0
Mon	29/06/2009z	08:00z	Monz	29/06/2009z	12:00z	240	97.02	0
Tue	30/06/2009z	08:00z	Tuez	30/06/2009z	12:00z	240	96.54	0
Wed	01/07/2009z	08:00z	Wedz	01/07/2009z	12:00z	240	96.19	0
Thu	02/07/2009z	08:00z	Thuz	02/07/2009z	12:00z	240	95.95	0
Fri	03/07/2009z	08:00z	Friz	03/07/2009z	12:00z	240	95.78	0
Sat	04/07/2009z	08:00z	Satz	04/07/2009z	12:00z	240	95.67	0
Sun	05/07/2009z	08:00z	Sunz	05/07/2009z	12:00z	240	95.6	0
Mon	06/07/2009z	08:00z	Monz	06/07/2009z	12:00z	240	95.54	0
Tue	07/07/2009z	08:00z	Tuez	07/07/2009z	12:00z	240	95.51	0
Wed	08/07/2009z	08:00z	Wedz	08/07/2009z	12:00z	240	95.48	0
Thu	09/07/2009z	08:00z	Thuz	09/07/2009z	12:00z	240	95.46	0
Fri	10/07/2009z	08:00z	Friz	10/07/2009z	12:00z	240	95.45	0
Sat	11/07/2009z	08:00z	Satz	11/07/2009z	12:00z	240	95.45	0
Sun	12/07/2009z	08:00z	Sunz	12/07/2009z	12:00z	240	95.44	0
Mon	13/07/2009z	08:00z	Monz	13/07/2009z	12:00z	240	95.44	0
Tue	14/07/2009z	08:00z	Tuez	14/07/2009z	12:00z	240	95.44	0
Wed	15/07/2009z	08:00z	Wedz	15/07/2009z	12:00z	240	95.43	0
Thu	16/07/2009z	08:00z	Thuz	16/07/2009z	12:00z	240	95.43	0
Fri	17/07/2009z	08:00z	Friz	17/07/2009z	12:00z	240	95.43	0
Sat	18/07/2009z	08:00z	Satz	18/07/2009z	12:00z	240	95.43	0
Sun	19/07/2009z	08:00z	Sunz	19/07/2009z	12:00z	240	95.43	0
Mon	20/07/2009z	08:00z	Monz	20/07/2009z	12:00z	240	95.43	0
Tue	21/07/2009z	08:00z	Tuez	21/07/2009z	12:00z	240	95.43	0
Wed	22/07/2009z	08:00z	Wedz	22/07/2009z	12:00z	240	95.43	0
Thu	23/07/2009z	08:00z	Thuz	23/07/2009z	12:00z	240	95.43	0
means						240	95.8	0.0

C.3.3 Table C.3.3. Syndicate C work period statistics for 20:00 to 24:00 h watch

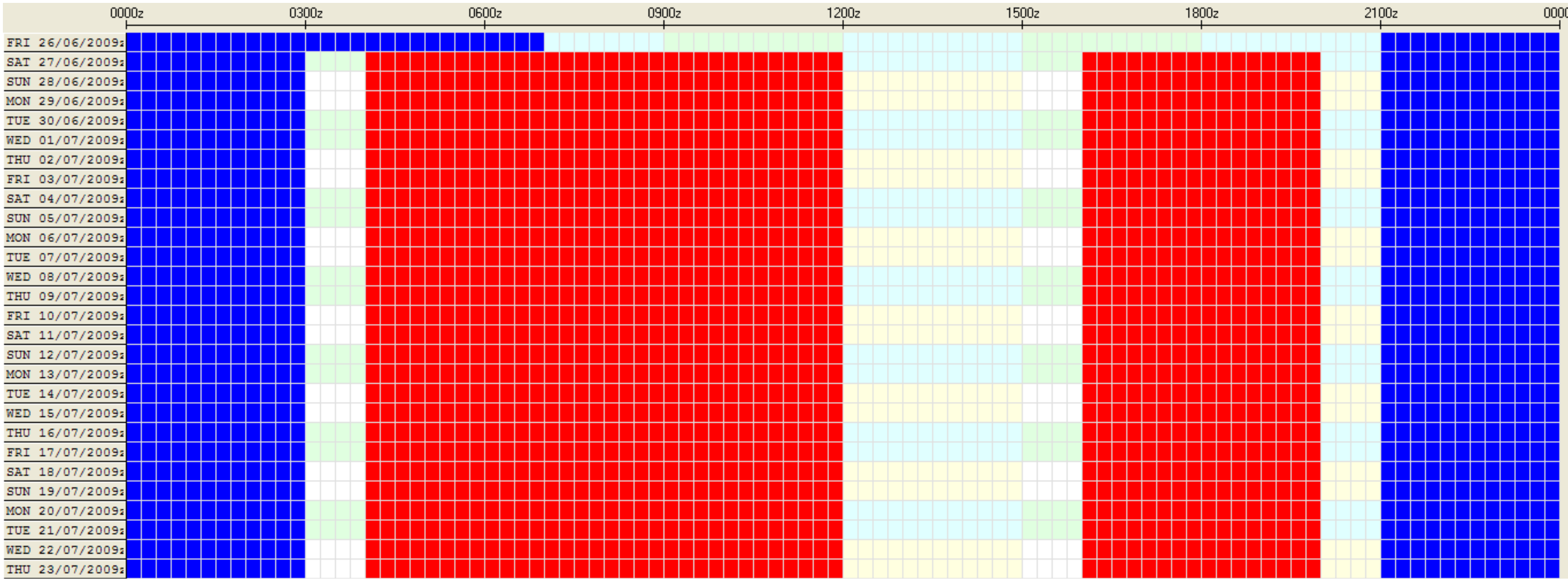
1-in-3 straight 4s C								
Start			work start		work stop		Stats	
Day	Date	Time	Day	Date	Time	Dur	Eff	%BCL
Fri	26/06/2009z	20:00z	Satz	27/06/2009z	00:00z	240	93.85	0
Sat	27/06/2009z	20:00z	Sunz	28/06/2009z	00:00z	240	93.75	0
Sun	28/06/2009z	20:00z	Monz	29/06/2009z	00:00z	240	94.09	0
Mon	29/06/2009z	20:00z	Tuez	30/06/2009z	00:00z	240	94.14	0
Tue	30/06/2009z	20:00z	Wedz	01/07/2009z	00:00z	240	94.04	0
Wed	01/07/2009z	20:00z	Thuz	02/07/2009z	00:00z	240	93.9	0
Thu	02/07/2009z	20:00z	Friz	03/07/2009z	00:00z	240	93.76	0
Fri	03/07/2009z	20:00z	Satz	04/07/2009z	00:00z	240	93.65	0
Sat	04/07/2009z	20:00z	Sunz	05/07/2009z	00:00z	240	93.57	0
Sun	05/07/2009z	20:00z	Monz	06/07/2009z	00:00z	240	93.51	0
Mon	06/07/2009z	20:00z	Tuez	07/07/2009z	00:00z	240	93.47	0
Tue	07/07/2009z	20:00z	Wedz	08/07/2009z	00:00z	240	93.44	0
Wed	08/07/2009z	20:00z	Thuz	09/07/2009z	00:00z	240	93.41	0
Thu	09/07/2009z	20:00z	Friz	10/07/2009z	00:00z	240	93.4	0
Fri	10/07/2009z	20:00z	Satz	11/07/2009z	00:00z	240	93.39	0
Sat	11/07/2009z	20:00z	Sunz	12/07/2009z	00:00z	240	93.38	0
Sun	12/07/2009z	20:00z	Monz	13/07/2009z	00:00z	240	93.38	0
Mon	13/07/2009z	20:00z	Tuez	14/07/2009z	00:00z	240	93.37	0
Tue	14/07/2009z	20:00z	Wedz	15/07/2009z	00:00z	240	93.37	0
Wed	15/07/2009z	20:00z	Thuz	16/07/2009z	00:00z	240	93.37	0
Thu	16/07/2009z	20:00z	Friz	17/07/2009z	00:00z	240	93.37	0
Fri	17/07/2009z	20:00z	Satz	18/07/2009z	00:00z	240	93.37	0
Sat	18/07/2009z	20:00z	Sunz	19/07/2009z	00:00z	240	93.37	0
Sun	19/07/2009z	20:00z	Monz	20/07/2009z	00:00z	240	93.37	0
Mon	20/07/2009z	20:00z	Tuez	21/07/2009z	00:00z	240	93.37	0
Tue	21/07/2009z	20:00z	Wedz	22/07/2009z	00:00z	240	93.37	0
Wed	22/07/2009z	20:00z	Thuz	23/07/2009z	00:00z	240	93.37	0
means						240	93.5	0.0

Annex D Proposed new CF 1-in-2 (8-4-4-8) watch system

D.1 Figure D1. Port syndicate, work from 04:00 to 12:00 h and 16:00 to 20:00 h with prescribed sleep from 21:00 to 03:00 h



D.1.1.1 **Figure D.1.1.1. Port Syndicate, work from 04:00 to12:00 h plus 20:00 to 24:00 h with sleep from 21:00 to 03:00 h**



D.1.2 Table D.1.2. Port syndicate work period statistics for 04:00 to 12:00 h watch

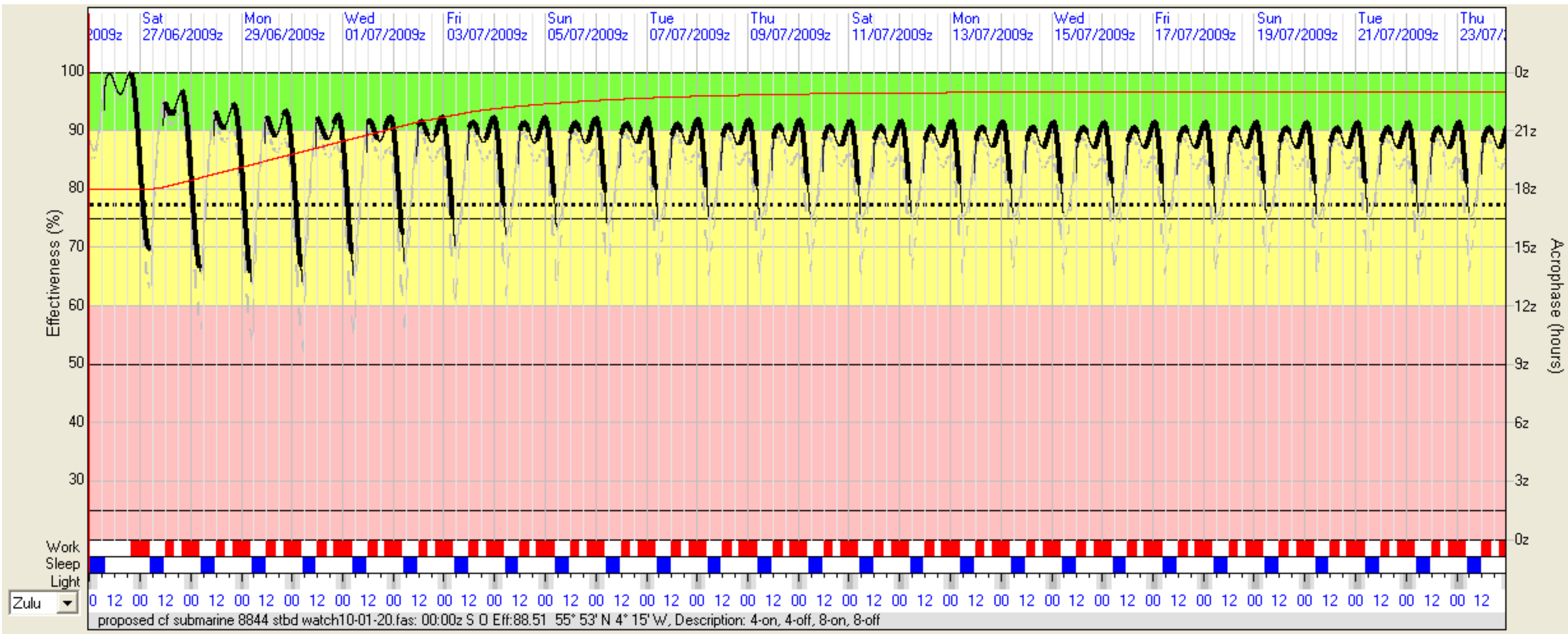
proposed 8-4-4-8 port syndicate								
Start		work start			work end	Stats		
Day	Date	Time	Day	Date	Time	Dur	Eff	%BCL
Sat	27/06/2009z	04:00z	Satz	27/06/2009z	12:00z	480	89.39	0
Sun	28/06/2009z	04:00z	Sunz	28/06/2009z	12:00z	480	86.36	0
Mon	29/06/2009z	04:00z	Monz	29/06/2009z	12:00z	480	85.81	0
Tue	30/06/2009z	04:00z	Tuez	30/06/2009z	12:00z	480	86.3	0
Wed	01/07/2009z	04:00z	Wedz	01/07/2009z	12:00z	480	87.03	0
Thu	02/07/2009z	04:00z	Thuz	02/07/2009z	12:00z	480	87.56	0
Fri	03/07/2009z	04:00z	Friz	03/07/2009z	12:00z	480	87.93	0
Sat	04/07/2009z	04:00z	Satz	04/07/2009z	12:00z	480	88.2	0
Sun	05/07/2009z	04:00z	Sunz	05/07/2009z	12:00z	480	88.39	0
Mon	06/07/2009z	04:00z	Monz	06/07/2009z	12:00z	480	88.53	0
Tue	07/07/2009z	04:00z	Tuez	07/07/2009z	12:00z	480	88.63	0
Wed	08/07/2009z	04:00z	Wedz	08/07/2009z	12:00z	480	88.71	0
Thu	09/07/2009z	04:00z	Thuz	09/07/2009z	12:00z	480	88.76	0
Fri	10/07/2009z	04:00z	Friz	10/07/2009z	12:00z	480	88.8	0
Sat	11/07/2009z	04:00z	Satz	11/07/2009z	12:00z	480	88.83	0
Sun	12/07/2009z	04:00z	Sunz	12/07/2009z	12:00z	480	88.85	0
Mon	13/07/2009z	04:00z	Monz	13/07/2009z	12:00z	480	88.86	0
Tue	14/07/2009z	04:00z	Tuez	14/07/2009z	12:00z	480	88.87	0
Wed	15/07/2009z	04:00z	Wedz	15/07/2009z	12:00z	480	88.88	0
Thu	16/07/2009z	04:00z	Thuz	16/07/2009z	12:00z	480	88.88	0
Fri	17/07/2009z	04:00z	Friz	17/07/2009z	12:00z	480	88.89	0
Sat	18/07/2009z	04:00z	Satz	18/07/2009z	12:00z	480	88.89	0
Sun	19/07/2009z	04:00z	Sunz	19/07/2009z	12:00z	480	88.89	0
Mon	20/07/2009z	04:00z	Monz	20/07/2009z	12:00z	480	88.89	0
Tue	21/07/2009z	04:00z	Tuez	21/07/2009z	12:00z	480	88.89	0
Wed	22/07/2009z	04:00z	Wedz	22/07/2009z	12:00z	480	88.89	0
Thu	23/07/2009z	04:00z	Thuz	23/07/2009z	12:00z	480	88.89	0
means						360	88.4	0

D.1.3 Table D.1.3. Port syndicate work period statistics for 16:00 to 20:00 h watch

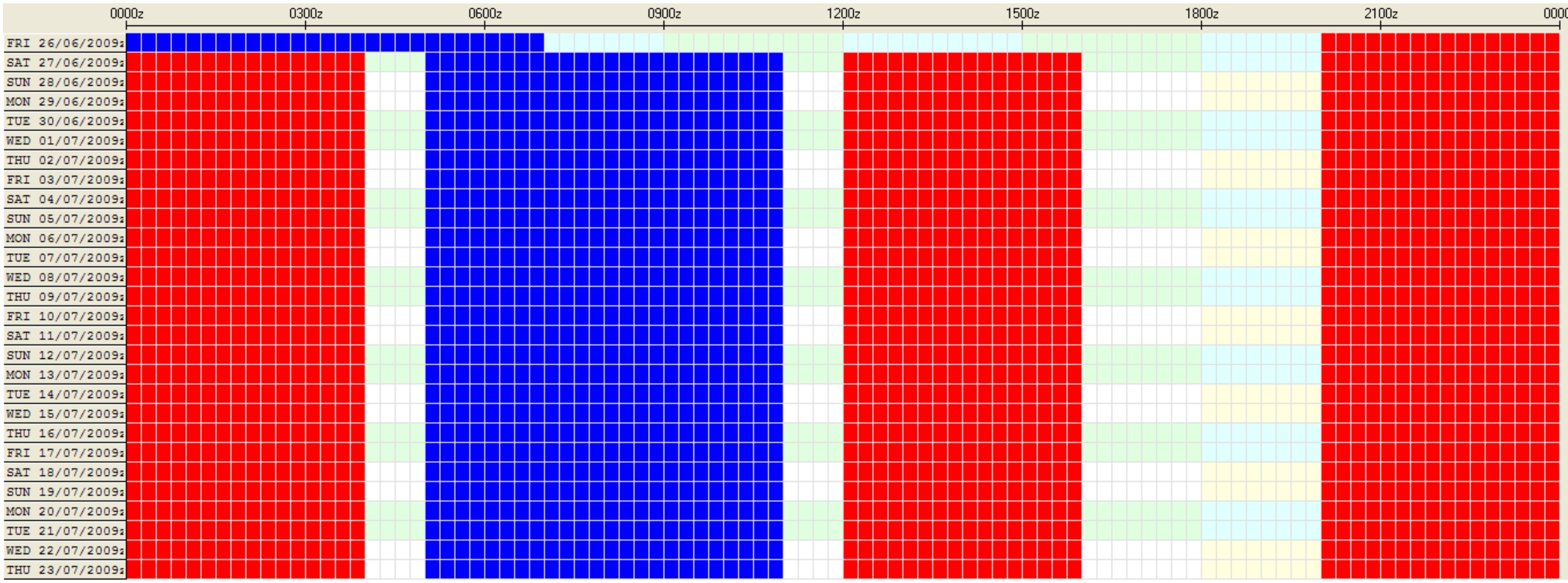
proposed 8-4-4-8 port syndicate

Start		work start			work end		Stats	
Day	Date	Time	Day	Date	Time	Dur	Eff	%BCL
Sat	27/06/2009z	16:00z	Satz	27/06/2009z	20:00z	240	91.03	0
Sun	28/06/2009z	16:00z	Sunz	28/06/2009z	20:00z	240	88.48	0
Mon	29/06/2009z	16:00z	Monz	29/06/2009z	20:00z	240	87.69	0
Tue	30/06/2009z	16:00z	Tuez	30/06/2009z	20:00z	240	87.41	0
Wed	01/07/2009z	16:00z	Wedz	01/07/2009z	20:00z	240	87.35	0
Thu	02/07/2009z	16:00z	Thuz	02/07/2009z	20:00z	240	87.41	0
Fri	03/07/2009z	16:00z	Friz	03/07/2009z	20:00z	240	87.52	0
Sat	04/07/2009z	16:00z	Satz	04/07/2009z	20:00z	240	87.65	0
Sun	05/07/2009z	16:00z	Sunz	05/07/2009z	20:00z	240	87.76	0
Mon	06/07/2009z	16:00z	Monz	06/07/2009z	20:00z	240	87.86	0
Tue	07/07/2009z	16:00z	Tuez	07/07/2009z	20:00z	240	87.94	0
Wed	08/07/2009z	16:00z	Wedz	08/07/2009z	20:00z	240	88	0
Thu	09/07/2009z	16:00z	Thuz	09/07/2009z	20:00z	240	88.04	0
Fri	10/07/2009z	16:00z	Friz	10/07/2009z	20:00z	240	88.08	0
Sat	11/07/2009z	16:00z	Satz	11/07/2009z	20:00z	240	88.1	0
Sun	12/07/2009z	16:00z	Sunz	12/07/2009z	20:00z	240	88.12	0
Mon	13/07/2009z	16:00z	Monz	13/07/2009z	20:00z	240	88.13	0
Tue	14/07/2009z	16:00z	Tuez	14/07/2009z	20:00z	240	88.14	0
Wed	15/07/2009z	16:00z	Wedz	15/07/2009z	20:00z	240	88.15	0
Thu	16/07/2009z	16:00z	Thuz	16/07/2009z	20:00z	240	88.15	0
Fri	17/07/2009z	16:00z	Friz	17/07/2009z	20:00z	240	88.16	0
Sat	18/07/2009z	16:00z	Satz	18/07/2009z	20:00z	240	88.16	0
Sun	19/07/2009z	16:00z	Sunz	19/07/2009z	20:00z	240	88.16	0
Mon	20/07/2009z	16:00z	Monz	20/07/2009z	20:00z	240	88.16	0
Tue	21/07/2009z	16:00z	Tuez	21/07/2009z	20:00z	240	88.16	0
Wed	22/07/2009z	16:00z	Wedz	22/07/2009z	20:00z	240	88.16	0
Thu	23/07/2009z	16:00z	Thuz	23/07/2009z	20:00z	240	88.16	0
means						360	88.1	0.0

D.2 Figure D2. Starboard syndicate, work from 12:00 to 16:00 h and 20:00 to 04:00 h with prescribed sleep from 05:00 to 11:00 h



D.2.1 Figure D.2.1. Starboard syndicate sleep (blue) and work (red) periods



D.2.2 Table D.2.2. Starboard syndicate work statistics for 12:00 to 16:00 h watch

proposed 8-4-4-8 stbd syndicate

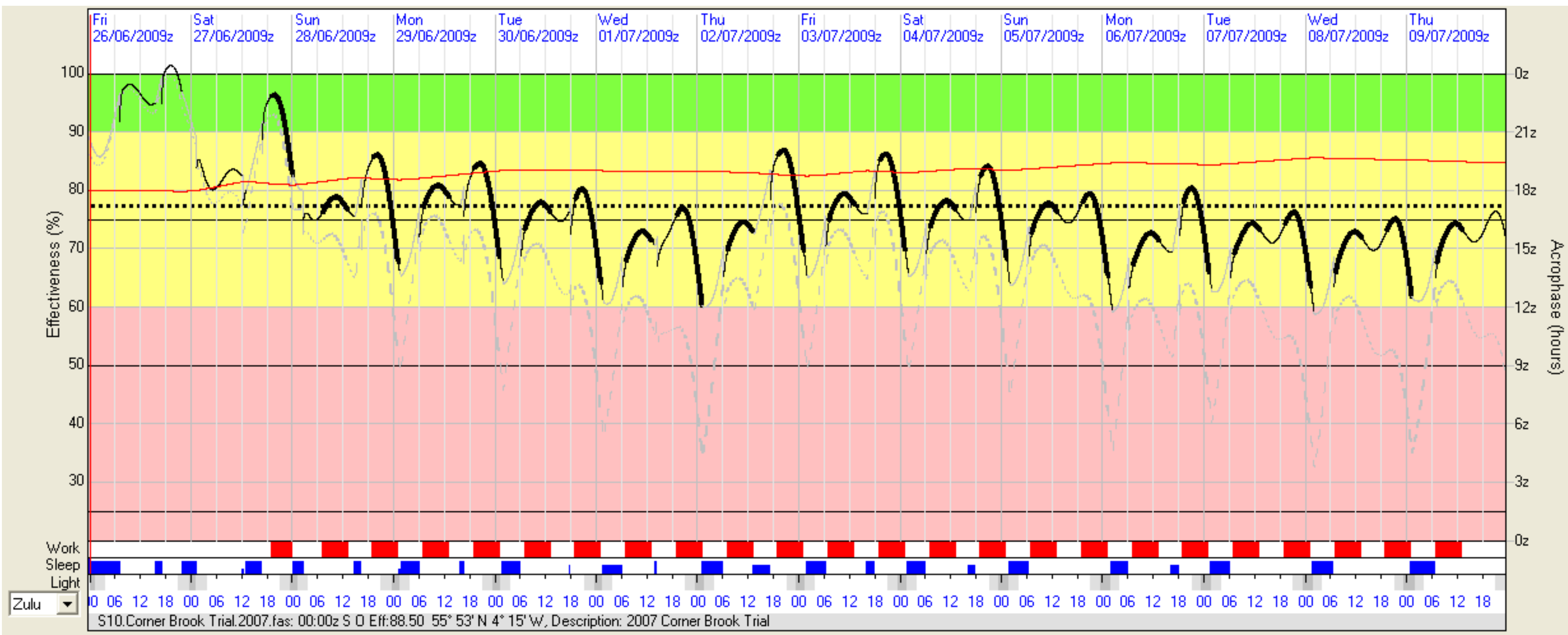
Start		Work start			Work end		Stats	
Day	Date	Time	Day	Date	Time	Dur	Eff	%BCL
Sat	27/06/2009z	12:00z	Satz	27/06/2009z	16:00z	240	93.4	0
Sun	28/06/2009z	12:00z	Sunz	28/06/2009z	16:00z	240	91.4	0
Mon	29/06/2009z	12:00z	Monz	29/06/2009z	16:00z	240	90.54	0
Tue	30/06/2009z	12:00z	Tuez	30/06/2009z	16:00z	240	90.4	0
Wed	01/07/2009z	12:00z	Wedz	01/07/2009z	16:00z	240	90.62	0
Thu	02/07/2009z	12:00z	Thuz	02/07/2009z	16:00z	240	90.87	0
Fri	03/07/2009z	12:00z	Friz	03/07/2009z	16:00z	240	90.94	0
Sat	04/07/2009z	12:00z	Satz	04/07/2009z	16:00z	240	90.93	0
Sun	05/07/2009z	12:00z	Sunz	05/07/2009z	16:00z	240	90.84	0
Mon	06/07/2009z	12:00z	Monz	06/07/2009z	16:00z	240	90.72	0
Tue	07/07/2009z	12:00z	Tuez	07/07/2009z	16:00z	240	90.59	0
Wed	08/07/2009z	12:00z	Wedz	08/07/2009z	16:00z	240	90.47	0
Thu	09/07/2009z	12:00z	Thuz	09/07/2009z	16:00z	240	90.36	0
Fri	10/07/2009z	12:00z	Friz	10/07/2009z	16:00z	240	90.26	0
Sat	11/07/2009z	12:00z	Satz	11/07/2009z	16:00z	240	90.18	0
Sun	12/07/2009z	12:00z	Sunz	12/07/2009z	16:00z	240	90.11	0
Mon	13/07/2009z	12:00z	Monz	13/07/2009z	16:00z	240	90.06	0
Tue	14/07/2009z	12:00z	Tuez	14/07/2009z	16:00z	240	90.01	0
Wed	15/07/2009z	12:00z	Wedz	15/07/2009z	16:00z	240	89.98	0
Thu	16/07/2009z	12:00z	Thuz	16/07/2009z	16:00z	240	89.96	0
Fri	17/07/2009z	12:00z	Friz	17/07/2009z	16:00z	240	89.94	0
Sat	18/07/2009z	12:00z	Satz	18/07/2009z	16:00z	240	89.92	0
Sun	19/07/2009z	12:00z	Sunz	19/07/2009z	16:00z	240	89.91	0
Mon	20/07/2009z	12:00z	Monz	20/07/2009z	16:00z	240	89.9	0
Tue	21/07/2009z	12:00z	Tuez	21/07/2009z	16:00z	240	89.89	0
Wed	22/07/2009z	12:00z	Wedz	22/07/2009z	16:00z	240	89.89	0
Thu	23/07/2009z	12:00z	Thuz	23/07/2009z	16:00z	240	89.88	0
mean						360	90.4	0.0

D.2.3 Table D.2.3. Starboard syndicate work statistics for 20:00 to 04:00 h watch

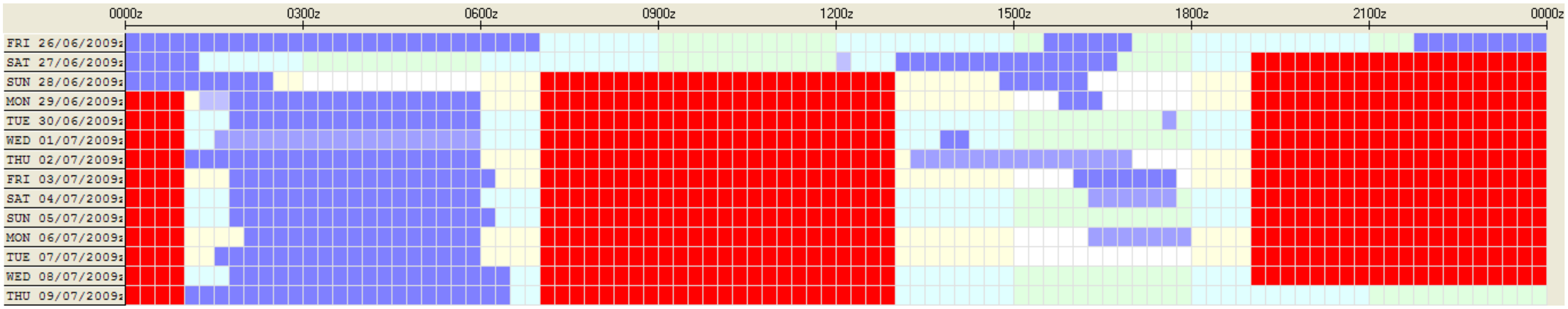
proposed	8-4-4-8 stbd syndicate							
Start		work start			work end		Stats	
Day	Date	Time	Day	Date	Time	Dur	Eff	%BCL
Fri	26/06/2009z	20:00z	Satz	27/06/2009z	04:00z	480	84.89	31.67
Sat	27/06/2009z	20:00z	Sunz	28/06/2009z	04:00z	480	82.98	35
Sun	28/06/2009z	20:00z	Monz	29/06/2009z	04:00z	480	83.18	32.08
Mon	29/06/2009z	20:00z	Tuez	30/06/2009z	04:00z	480	84.21	26.67
Tue	30/06/2009z	20:00z	Wedz	01/07/2009z	04:00z	480	85.6	19.79
Wed	01/07/2009z	20:00z	Thuz	02/07/2009z	04:00z	480	87.01	11.88
Thu	02/07/2009z	20:00z	Friz	03/07/2009z	04:00z	480	88.07	5
Fri	03/07/2009z	20:00z	Satz	04/07/2009z	04:00z	480	88.67	0
Sat	04/07/2009z	20:00z	Sunz	05/07/2009z	04:00z	480	88.96	0
Sun	05/07/2009z	20:00z	Monz	06/07/2009z	04:00z	480	89.09	0
Mon	06/07/2009z	20:00z	Tuez	07/07/2009z	04:00z	480	89.13	0
Tue	07/07/2009z	20:00z	Wedz	08/07/2009z	04:00z	480	89.11	0
Wed	08/07/2009z	20:00z	Thuz	09/07/2009z	04:00z	480	89.07	0
Thu	09/07/2009z	20:00z	Friz	10/07/2009z	04:00z	480	89.02	0
Fri	10/07/2009z	20:00z	Satz	11/07/2009z	04:00z	480	88.97	0
Sat	11/07/2009z	20:00z	Sunz	12/07/2009z	04:00z	480	88.92	0
Sun	12/07/2009z	20:00z	Monz	13/07/2009z	04:00z	480	88.88	0
Mon	13/07/2009z	20:00z	Tuez	14/07/2009z	04:00z	480	88.84	0
Tue	14/07/2009z	20:00z	Wedz	15/07/2009z	04:00z	480	88.81	0
Wed	15/07/2009z	20:00z	Thuz	16/07/2009z	04:00z	480	88.79	0
Thu	16/07/2009z	20:00z	Friz	17/07/2009z	04:00z	480	88.77	0
Fri	17/07/2009z	20:00z	Satz	18/07/2009z	04:00z	480	88.75	0
Sat	18/07/2009z	20:00z	Sunz	19/07/2009z	04:00z	480	88.74	0
Sun	19/07/2009z	20:00z	Monz	20/07/2009z	04:00z	480	88.73	0
Mon	20/07/2009z	20:00z	Tuez	21/07/2009z	04:00z	480	88.72	0
Tue	21/07/2009z	20:00z	Wedz	22/07/2009z	04:00z	480	88.72	0
Wed	22/07/2009z	20:00z	Thuz	23/07/2009z	04:00z	480	88.71	0
mean						480	87.90	6.00

Annex E Current 1-in-2 watch schedule (6-6-6-6)

E.1 Figure E1. Front watch syndicate, (work from 07:00 to 13:00 h and 19:00 to 01:00 h with actigraphically measured sleep during 2007 at-sea trial on Corner Brook)



E.1.1 Figure E.1.1. Front watch syndicate sleep (blue) and work (red) periods



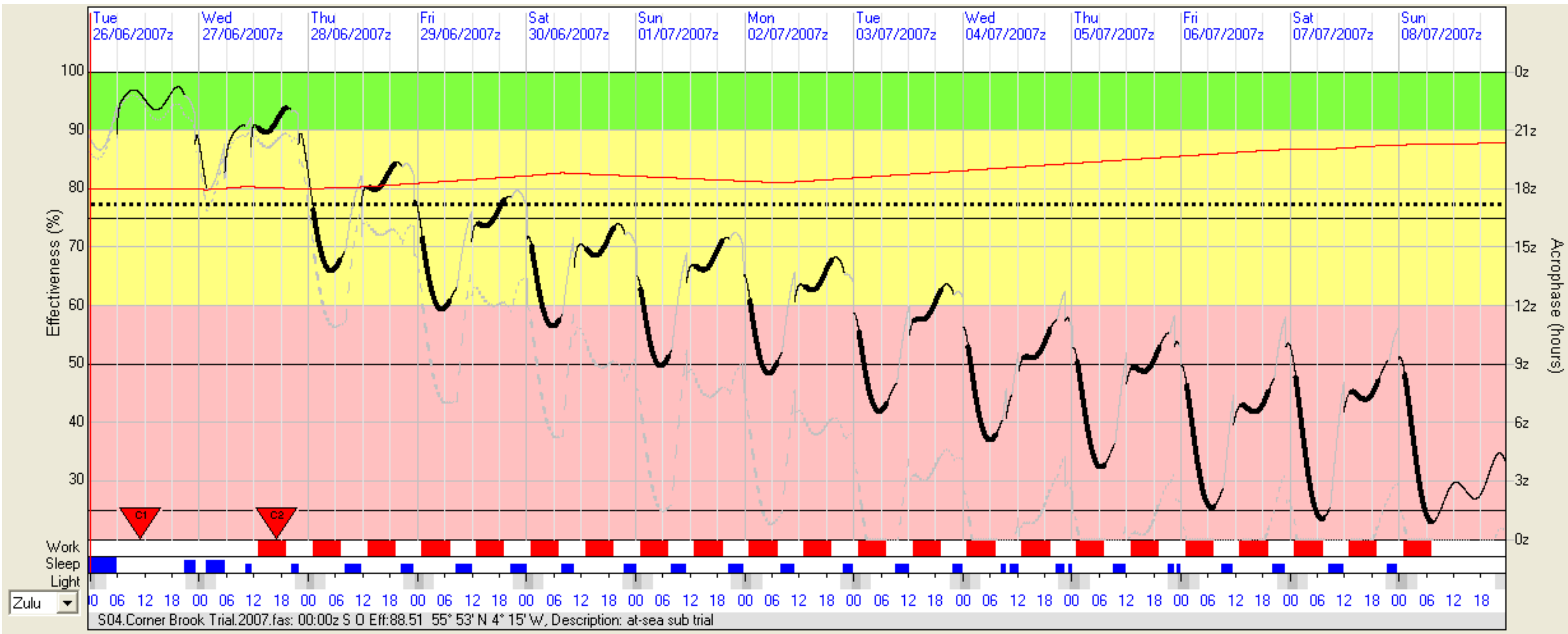
E.1.2 Table E.1.2. Front watch syndicate work statistics for 07:00 to 13:00 h watch

Corner Brook trial. front watch								
Start		work start			work end		Stats	
Day	Date	Time	Day	Date	Time	Dur	Eff	%BCL
Sun	28/06/2009z	07:00z	Sunz	28/06/2009z	13:00z	360	77.95	30.28
Mon	29/06/2009z	07:00z	Monz	29/06/2009z	13:00z	360	79.83	3.06
Tue	30/06/2009z	07:00z	Tuez	30/06/2009z	13:00z	360	76.73	64.72
Wed	01/07/2009z	07:00z	Wedz	01/07/2009z	13:00z	360	71.68	100
Thu	02/07/2009z	07:00z	Thuz	02/07/2009z	13:00z	360	73.36	100
Fri	03/07/2009z	07:00z	Friz	03/07/2009z	13:00z	360	78.24	19.72
Sat	04/07/2009z	07:00z	Satz	04/07/2009z	13:00z	360	77.07	52.22
Sun	05/07/2009z	07:00z	Sunz	05/07/2009z	13:00z	360	76.51	72.78
Mon	06/07/2009z	07:00z	Monz	06/07/2009z	13:00z	360	71.23	100
Tue	07/07/2009z	07:00z	Tuez	07/07/2009z	13:00z	360	72.96	100
Wed	08/07/2009z	07:00z	Wedz	08/07/2009z	13:00z	360	71.17	100
Thu	09/07/2009z	07:00z	Thuz	09/07/2009z	13:00z	360	72.73	100
means						357.5	75.0	70.2

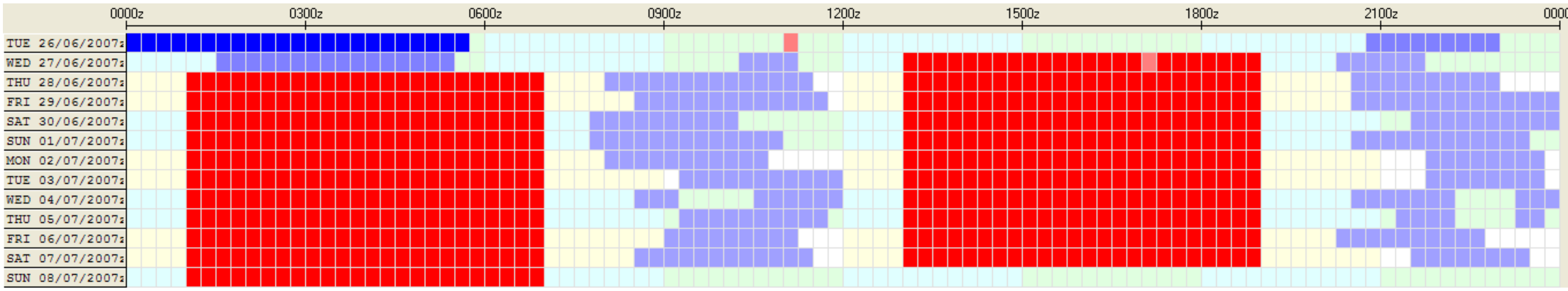
E.1.3 Table E.1.3. Front watch syndicate work statistics for 19:00 to 01:00 h watch

Corner Brook trial.front watch								
Start		work start			work end		Stats	
Day	Date	Time	Day	Date	Time	Dur	Eff	%BCL
Sat	27/06/2009z	19:00z	Sunz	28/06/2009z	00:00z	300	92.16	0
Sun	28/06/2009z	19:00z	Monz	29/06/2009z	01:00z	360	80.52	29.44
Mon	29/06/2009z	19:00z	Tuez	30/06/2009z	01:00z	360	80.15	28.06
Tue	30/06/2009z	19:00z	Wedz	01/07/2009z	01:00z	360	75.79	46.11
Wed	01/07/2009z	19:00z	Thuz	02/07/2009z	01:00z	360	72.33	100
Thu	02/07/2009z	19:00z	Friz	03/07/2009z	01:00z	360	81.88	23.61
Fri	03/07/2009z	19:00z	Satz	04/07/2009z	01:00z	360	81.66	23.06
Sat	04/07/2009z	19:00z	Sunz	05/07/2009z	01:00z	360	79.84	28.33
Sun	05/07/2009z	19:00z	Monz	06/07/2009z	01:00z	360	75.75	46.11
Mon	06/07/2009z	19:00z	Tuez	07/07/2009z	01:00z	360	76.63	40
Tue	07/07/2009z	19:00z	Wedz	08/07/2009z	01:00z	360	73.08	100
Wed	08/07/2009z	19:00z	Thuz	09/07/2009z	01:00z	360	71.76	100
means						357.5	78.5	47.1

E.2 Back watch syndicate, (work from 01:00 to 07:00 h and 13:00 to 19:00 h with actigraphically measured sleep during 2007 at-sea trial on Corner Brook)



E.2.1 Figure E.2.1. Back watch syndicate sleep (blue) and work (red) periods



E.2.2 Table E.2.2. Back watch syndicate work period statistics for 01:00 to 07:00 h watch

Corner Brook Trial back watch								
Start		work start			work end		Stats	
Day	Date	Time	Day	Date	Time	Dur	Eff	%BCL
Thu	28/06/2007z	01:00z	Thuz	28/06/2007z	07:00z	360	68.49	100
Fri	29/06/2007z	01:00z	Friz	29/06/2007z	07:00z	360	62.4	100
Sat	30/06/2007z	01:00z	Satz	30/06/2007z	07:00z	360	60.25	100
Sun	01/07/2007z	01:00z	Sunz	01/07/2007z	07:00z	360	53.29	100
Mon	02/07/2007z	01:00z	Monz	02/07/2007z	07:00z	360	51.56	100
Tue	03/07/2007z	01:00z	Tuez	03/07/2007z	07:00z	360	45.5	100
Wed	04/07/2007z	01:00z	Wedz	04/07/2007z	07:00z	360	41.57	100
Thu	05/07/2007z	01:00z	Thuz	05/07/2007z	07:00z	360	38.03	100
Fri	06/07/2007z	01:00z	Friz	06/07/2007z	07:00z	360	32.59	100
Sat	07/07/2007z	01:00z	Satz	07/07/2007z	07:00z	360	32.07	100
Sun	08/07/2007z	01:00z	Sunz	08/07/2007z	07:00z	360	32.45	100
means						360	47.1	100.0

E.2.3 Table E.2.3. Back watch syndicate work period statistics for 13:00 to 19:00 h watch

Corner Brook Trial back watch

Start		work start			work end	Stats		
Day	Date	Time	Day	Date	Time	Dur	Eff	%BCL
Wed	27/06/2007z	13:00z	Wedz	27/06/2007z	19:00z	360	91.14	0
Thu	28/06/2007z	13:00z	Thuz	28/06/2007z	19:00z	360	81.35	0
Fri	29/06/2007z	13:00z	Friz	29/06/2007z	19:00z	360	74.95	90.56
Sat	30/06/2007z	13:00z	Satz	30/06/2007z	19:00z	360	69.97	100
Sun	01/07/2007z	13:00z	Sunz	01/07/2007z	19:00z	360	67.67	100
Mon	02/07/2007z	13:00z	Monz	02/07/2007z	19:00z	360	64.28	100
Tue	03/07/2007z	13:00z	Tuez	03/07/2007z	19:00z	360	58.97	100
Wed	04/07/2007z	13:00z	Wedz	04/07/2007z	19:00z	360	52.28	100
Thu	05/07/2007z	13:00z	Thuz	05/07/2007z	19:00z	360	49.76	100
Fri	06/07/2007z	13:00z	Friz	06/07/2007z	19:00z	360	42.72	100
Sat	07/07/2007z	13:00z	Satz	07/07/2007z	19:00z	360	44.76	100
means						360	63.4	81.0

Annex F Sleep, Activity, Fatigue and Task Effectiveness (SAFTE) Model

F.1 Fatigue Avoidance Scheduling Tool (*FAST*™)

The Sleep, Activity, Fatigue and Task Effectiveness (SAFTE) model integrates quantitative information about (1) circadian rhythms in metabolic rate, (2) cognitive performance recovery rates associated with sleep, and cognitive performance decay rates associated with wakefulness, and (3) cognitive performance effects associated with sleep inertia to produce a 3-process model of human cognitive effectiveness.

The SAFTE model has been under development by Dr. Steven Hursh for more than a decade and a half. Dr. Hursh, formerly a research scientist with the US Army, is the president of IBR Inc. and an adjunct professor at Johns Hopkins University. Dr. Hursh is the sole inventor of the SAFTE model and the patent is held by the US Army. He is also the co-inventor of the Fatigue Avoidance Scheduling Tool (FAST™), the fatigue analysis software system based on the SAFTE model and used in conduction the modeling analysis in this report.

The general architecture of the SAFTE model is shown in Figure 1. A circadian process influences both cognitive effectiveness and sleep regulation. Sleep regulation is dependent upon hours of sleep, hours of wakefulness, current sleep debt, the circadian process and sleep fragmentation (awakenings during a sleep period). Cognitive effectiveness is dependent upon the current balance of the sleep regulation process, the circadian process, and sleep inertia.

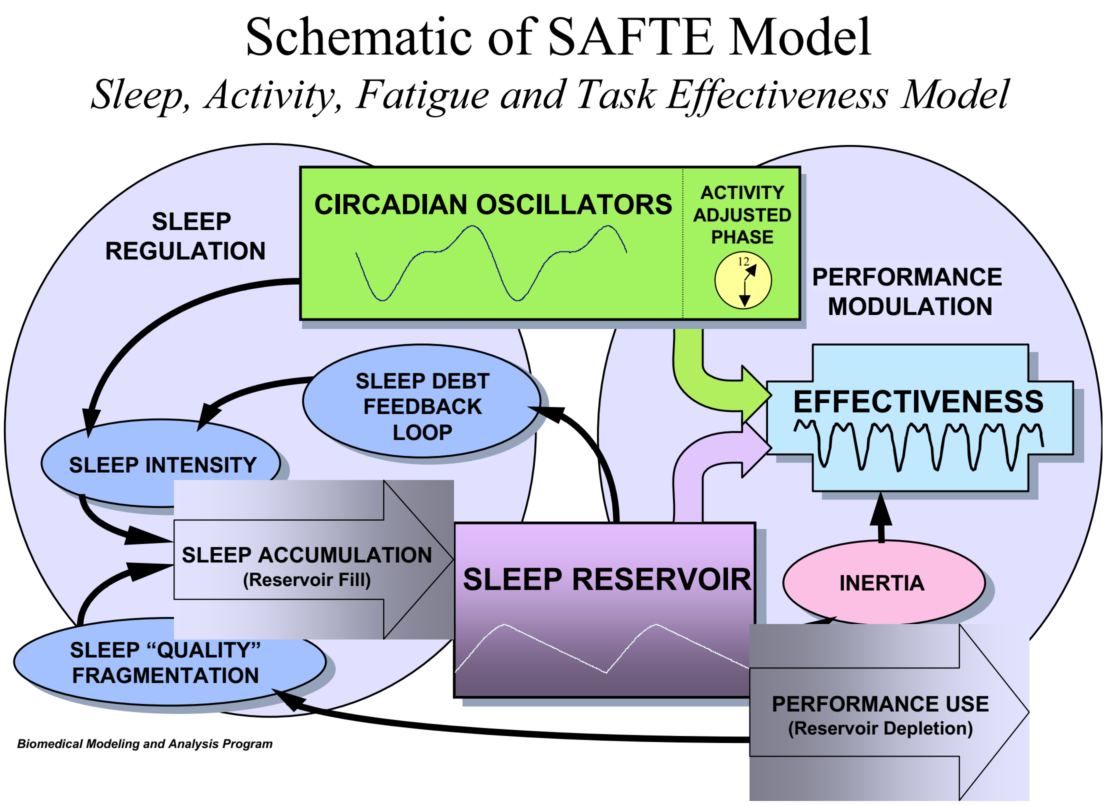


Figure 1. Schematic of SAFTE Model

SAFTE has been validated against group mean data from a Canadian laboratory and other laboratories that were not used in the model's development (Hursh et al., 2004). The SAFTE model has received broad scientific review and the US DoD considers it the most complete, accurate, and operationally practical model available to aid operator scheduling. It has been adopted as the US DoD model for warfighter fatigue assessment and is now being used by the US Federal Aviation Administration and US Federal Railroad Administration for fatigue assessments in transportation. The science behind SAFTE led to the development of FAST™ (Fatigue Avoidance and Safety Tool), a computer application designed to predict and prevent fatigue in operational settings. The output of FAST is an empirically-derived performance effectiveness score used to quantify potential fatigue risks. Both the SAFTE model and FAST application are fatigue management tools used in a variety of applications. The model has been independently tested and compared to other models from around the world and found to have the least error of any available model (Van Dongen, 2004). It has been validated as a predictor of accidents in operational environments (Hursh, et al., 2006). The FAST software is currently licensed to fourteen major aviation carriers and seventeen government regulatory agencies worldwide for fatigue assessment in the workplace, including several Canadian agencies.

The model does not incorporate the effects of pharmacological alertness aids; chronic fatigue (motivational exhaustion); chronic fatigue syndrome; fatiguing physiological factors such as exercise, hypoxia or acceleration; sleep disorders; or the fatiguing effects of infection.

The SAFTE Model has a number of essential features that distinguish it from other attempts to model sleep and fatigue (Table F-1). Together, these features of the model allow it to make very accurate predictions of performance under a variety of work schedules and levels of sleep deprivation.

Table F-1. SAFTE model essential features.

KEY FEATURES	ADVANTAGES
✓ Iterative Process Simulation Model	• Effects of any schedule down to the minute • Effects of any sleep pattern • Adaptive to actigraph or temperature data
✓ Homeostatic	• Declining sleep intensity during sleep period • Adaptive equilibrium of performance under less than optimal schedules of sleep
✓ Multi-oscillator Circadian Process	• Asymmetrical cycle of performance, 24 & 12 hr cos
✓ Clock Driven Circadian Process ✓ Event Driven Sleep-Wake Cycle	• Mid-afternoon dip in performance • Predominant early morning nadir in performance
✓ Circadian Variation in Sleep Propensity and Intensity	• Time-of-day variations in sleep benefit. • Limits on performance with day time sleep
✓ Sleep Quality and Fragmentation	• Environmental effects on sleep quality • Sleep Apnea
✓ Sleep Inertia	• Post-awakening slowing of performance
✓ Dynamic adaptive Circadian Phase	• Shift schedules and "jet lag" effects • Duration of adjustment
✓ Rate of Phase Adjustment is Solar Light Sensitive	• Rate of phase adjustment to shift work is much slower than time zone adjustment • Reflects effects of light and social cues
✓ Both Acute and Chronic Sleep Restrictions and Rate of Recovery	• Consistent with recent reports of performance under chronic sleep restriction • Consistent with slow rates of recovery following chronic schedules of sleep restriction
✓ Task Effectiveness Parameters	• Predict variations relevant operator performance

The Fatigue Avoidance Scheduling Tool (*FAST*™) is based upon the SAFTE model. *FAST*™, developed by NTI, Inc. with Dr. Hursh as an AF SBIR (Air Force, Small Business Innovative Research) product, is a Windows® program that allows planners and schedulers to estimate the average effects of various schedules on human performance. It allows work and sleep data entry in graphic and text formats. A watch schedule comprised on alternating 8-hr and 4-hr watches is shown as red bands on the time line across the bottom of the graphic presentation format in Figure 2. Average performance effectiveness for work periods may be extracted and printed as shown in the table below the figure.

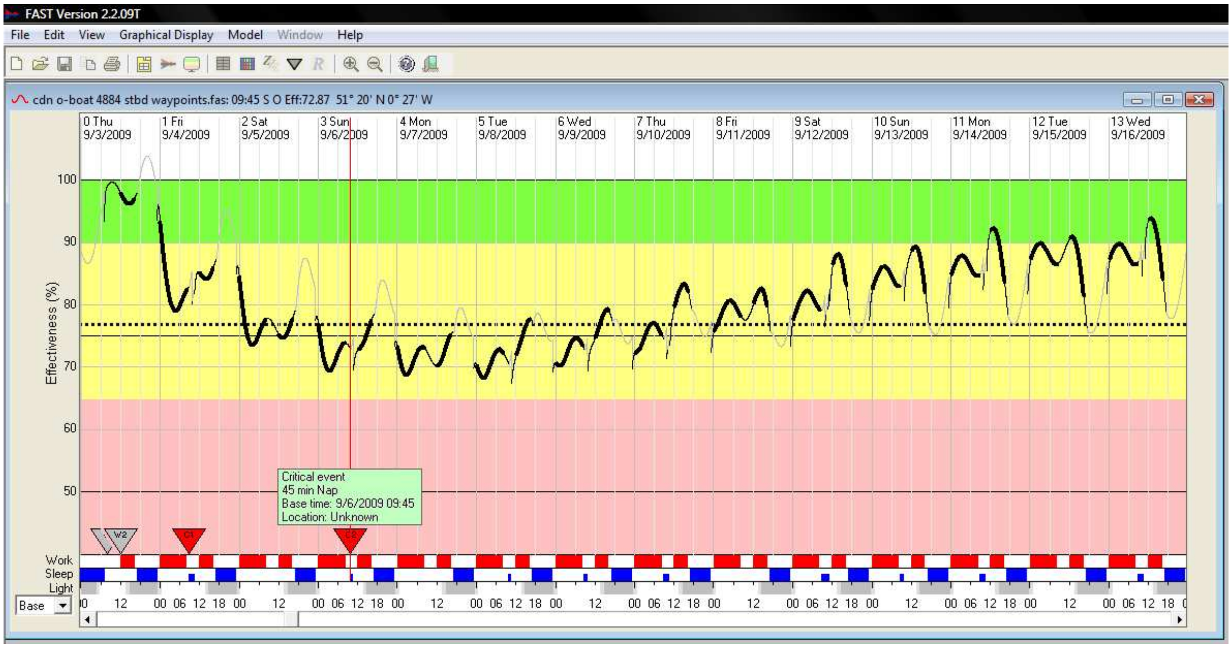


Figure 2: Sample FAST^tm display. The red bars along the horizontal axis indicate work intervals; the blue bars indicate sleep periods. The grey triangles represent waypoint changes that control the amount of light available at awakening (grey bars below graph indicate "night" lighting) and during various phases of the circadian rhythm. The red triangles indicate events in the schedule, such as short naps. The table shows the mission split into 8-hr and 4-hr watches starting at midnight and noon, respectively. This chart illustrates the week of adaptation to the phase shift of sleep and wake timing at the start of the mission.

Wake					**Work**					
Statistics					Statistics					% Below Criterion Level
Day	Start Date	Time	Duration	Mean Effectiveness	Day	Start Date	Time	Duration	Mean Effectiveness	
Thu	9/3/2009	7:00	600	97.92	Thu	9/3/2009	12:00	240	96.72	0
Thu	9/3/2009	23:00	585	83.8	Fri	9/4/2009	0:00	480	82.49	0
Fri	9/4/2009	10:20	400	84.95	Fri	9/4/2009	12:00	240	84.66	0
Fri	9/4/2009	23:00	1080	76.95	Sat	9/5/2009	0:00	480	76.37	67.5
Sat	9/5/2009	23:00	645	72.67	Sat	9/5/2009	12:00	240	75.56	88.33
Sun	9/6/2009	10:30	390	74.57	Sun	9/6/2009	0:00	480	71.84	100
Sun	9/6/2009	23:00	1080	71.83	Sun	9/6/2009	12:00	240	74.72	90.83
Mon	9/7/2009	23:00	645	70.69	Mon	9/7/2009	0:00	480	71.02	100
Tue	9/8/2009	10:30	390	74.42	Mon	9/7/2009	12:00	240	72.42	100
Tue	9/8/2009	23:00	585	72.48	Tue	9/8/2009	0:00	480	70.57	100
Wed	9/9/2009	9:30	450	76.23	Tue	9/8/2009	12:00	240	75.21	76.67
Wed	9/9/2009	23:00	585	74.82	Wed	9/9/2009	0:00	480	72.68	100
					Wed	9/9/2009	12:00	240	77.71	33.33

Sleep periods are shown as blue bands across the time line, below the red bands. Note that there each day has one major sleep period of excellent sleep and occasional short naps of fair quality, shown as shorter blue bars during the 4-hr breaks.

The vertical axis of the diagram represents human performance calibrated to the percent change in speed on a psychomotor vigilance task. The axis is scaled from zero to 100%. The oscillating line in the diagram represents expected group average performance on these tasks as determined by time of day, biological rhythms, time spent awake, and amount of sleep. We would expect the predicted performance of half of the people in a group to fall below this line.

The green area on the chart ends at the time for normal sleep, ~90% effectiveness.

The yellow indicates caution.

The area from the dotted line to the red area represents performance level during the nadir and during a 2nd day without sleep.

The red area represents performance effectiveness after 2 days and a night of sleep deprivation.

The expected level of performance effectiveness is highly correlated to detailed analysis of data from participants engaged in the performance of cognitive tasks during several sleep deprivation studies conducted by the Army, Air Force and Canadian researchers. The algorithm that creates the predictions has been under development for two decades and represents the most advanced information available at this time.

Annex F References

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List of symbols/abbreviations/acronyms/initials

BAC	Blood Alcohol Content
BCL	Below Criterion Line
BOI	Board of Inquiry
CF	Canadian Forces
DRDC	Defence Research & Development Canada
FAST™	Fatigue Avoidance Scheduling Tool
HMCS	Her Majesty's Canadian Ship
SAFTE	SAFety and Task Effectiveness model
REM	Rapid Eye Movement sleep
RN	Royal Navy
RAN	Royal Australian Navy
RNLN	Royal Netherlands Navy
USN	United States navy

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(U) Background. The summer 2007 at−sea trial to evaluate the CF submarine watch schedule revealed dangerously low levels of modeled cognitive effectiveness among the crew. In response, DRDC Toronto hosted an International Submarine Watch Schedule Symposium (CF, USN, RN, RAN, and RNLN) to review International experience with National watch schedule challenges and to model alternative watch schedules that would be more sparing of crew performance. Methods. Three alternative watch schedule systems were modeled (1−in−3 straight eights, 1−in−3 straight fours, and 1−in−2 (8−4−4−8)). These three alternative watch systems were compared to the current 1−in−2 (6−6−6−6) CF submarine watch schedule. Results. The mean modeled cognitive effectiveness for all watches within each system were 96%, 91%, 89% and 66% for the 1−in−3 straight eights, 1−in−3 straight fours, 1−in−2 (8−4−4−8) and the current CF 1−in−2 (6−6−6−6) respectively. Discussion. While it is evident that the best of these alternative watch schedules is the 1−in−3 straight eights (96% mean effectiveness), it is also evident that only larger submarines with larger crews (nuclear−powered USN and RN ballistic missile submarines and nuclear−powered USN attack submarines) have employed such a watch system. Smaller diesel−powered attack submarines have small crews which makes it impossible for such boats to operate either the 1−in−3 straight eights or the 1−in−3 straight fours. Essentially, small diesel−powered submarines must employ a 1−in−2 watch system (i.e. work 12 hours each day). The current CF submarine system is 1−in−2 and involves two 6−hr daily watch periods for each of the ‘front’ and ‘back’ syndicates. The alternative 1−in−2 (8−4−4−8) watch schedule has an 8−hr and a 4−hr daily watch period for each of the ‘port’ and ‘starboard’ syndicates. This alternative 1−in−2 (8−4−4−8) watch system is almost as good as the 1−in−3 straight fours (i.e. mean overall cognitive effectiveness of 89% for the 1−in−2 8−4−4−8 system vs. 91% 1−in−3 straight fours system) and much better than the overall 66% mean cognitive effectiveness of the current 1−in−2 (6−6−6−6) 1−in−2 watch system. Conclusion. The alternative 1−in−2 watch system represents a 23% overall increase in cognitive effectiveness over the current 1−in−2 watch system. Recommendations. The 1−in−2 (8−4−4−8) watch system should be evaluated in an at−sea trial with a view to adapting operational routines to that watch system, and if possible, the system should be incorporated on all CF submarines.

(U) Contexte. Un essai en mer réalisé à l’été 2007 afin d’évaluer l’horaire de garde à bord des sous−marins des FC a révélé des niveaux dangereusement faibles d’efficacité cognitive des membres de l’équipage. Dans la foulée de ces résultats, RDDC Toronto a organisé un symposium international sur les horaires de garde à bord des sous−marins (FC, USN, RN, RAN et RNLN) permettant de faire le point sur la façon dont les différents pays relèvent les défis imposés par leurs horaires de garde et de préparer des modèles d’horaires qui hypothéqueraient moins le rendement de l’équipage. Méthodologie : Trois horaires différents ont été préparés [1 tour sur 3 de huit heures, 1 tour sur 3 de quatre heures, et 1 tour sur 2 (8−4−4−8)]. Ces trois horaires possibles ont été comparés au système actuel de 1 tour sur 2 (6−6−6−6) en vigueur à bord des sous−marins des FC. Résultats : L’efficacité cognitive moyenne observée des sous−mariniers durant tous les tours de garde de chaque système s’est établie à 96 %, 91 % et 89 %, et à 66 % pour les tours de garde 1 sur 3 de huit heures, 1 sur 3 de quatre heures, 1 sur 2 (8−4−4−8) et le tour 1 sur 2 (6−6−6−6) actuel des FC, respectivement. Analyse. Bien que l’horaire de garde alternatif de 1 tour sur 3 de huit heures soit manifestement le meilleur des trois horaires proposés (efficacité moyenne de 96 %), on a constaté que seuls les gros sous−marins dotés

d'équipages plus nombreux (sous−marins à propulsion nucléaire de la USN, sous−marins lance−missiles balistiques de la RN et sous−marins d'attaque à propulsion nucléaire de la USN) appliquent cet horaire. Les petits sous−marins d'attaque à propulsion diésel ont des équipages réduits, ce qui les empêche d'utiliser un horaire de garde de 1 tour sur 3 de huit heures ou de 1 tour sur trois de quatre heures. Essentiellement, les petits sous−marins à propulsion diésel doivent utiliser un horaire de garde de 1 tour sur 2 (soit 12 heures ouvrables par jour). L'horaire de garde en usage à bord des sous−marins des FC est le 1 tour sur 2 qui suppose deux périodes de garde de six heures chaque jour pour les équipes de l'avant et de l'arrière. L'horaire de garde alternatif de 1 tour sur 2 (8−4−4−8) comporte des périodes de huit et de quatre heures chaque jour pour chacune des équipes de bâbord et de tribord. Cette solution équivaut presque à l'horaire de 1 tour sur 3 de quatre heures et 1 tour sur 3 de huit heures (efficacité cognitive moyenne de 89 % pour l'horaire de 1 tour sur 2 (8−4−4−8) comparativement à une efficacité cognitive de 96 % pour l'horaire de 1 tour sur trois de quatre heures ainsi que pour l'horaire de 1 tour sur trois de huit heures) et elle est de beaucoup supérieure à l'horaire de garde actuel de 1 tour sur 2 (6−6−6−6) dont l'efficacité cognitive moyenne est de 66 %. Conclusion. L'horaire de garde alternatif qui consiste à servir 1 tour sur 2 correspond à un accroissement global de 23 % de l'efficacité cognitive par rapport à l'horaire actuel de 1 tour sur 2. Recommandations. On devrait évaluer l'horaire de garde à 1 tour sur 2 (8−4−4−8) dans le cadre d'un essai en mer dans l'optique d'y adapter les tâches quotidiennes courantes et, si c'est possible, appliquer cet horaire à tous les sous−marins des FC.

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