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ANALYSIS OF ALTERNATIVE WATCH SCHEDULES FOR SHIPBOARD OPERATIONS: A GUIDE FOR COMMANDERS

by

Donald A. Roberts

March 2012

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In recent years "optimal" manning has been implemented on U.S. Navy surface ships where crew sizes have been reduced. This undermanning has resulted in a requirement for sailors to stand longer watches and get less sleep, making for less effective sailors while standing watch. Alternative watch schedules can be used that minimize fatigue of sailors while on watch. The first objective of this study is to analyze a USS San Jacinto crew survey, which compared an alternative watch schedule to more traditional watch schedules. The second objective is to create and analyze various notional use cases of watch schedules to maximize predicted performance while on watch. Crew fatigue is analyzed using the Fatigue Avoidance Scheduling Tool (FAST) program for various cases of notional watch. It was found from the USS San Jacinto survey results that enlisted and officers both preferred the alternative 3/9 watch schedule when compared to other watches that the crew members stood in the past. When comparing the predicted effectiveness while on watch, it was found that the 3/9 watch was best for four section duty, the straight fours was best for three section duty, and the 12/12 watch was best for two section duty.

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ANALYSIS OF ALTERNATIVE WATCH SCHEDULES FOR SHIPBOARD OPERATIONS: A GUIDE FOR COMMANDERS

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ABSTRACT

In recent years "optimal" manning has been implemented on U.S. Navy surface ships where crew sizes have been reduced. This undermanning has resulted in a requirement for sailors to stand longer watches and get less sleep, making for less effective sailors while standing watch. Alternative watch schedules can be used that minimize fatigue of sailors while on watch. The first objective of this study is to analyze a USS San Jacinto (CG-56) crew survey, which compared an alternative watch schedule to more traditional watch schedules. The second objective is to create and analyze various notional use cases of watch schedules to maximize predicted performance while on watch. Crew fatigue is analyzed using the Fatigue Avoidance Scheduling Tool (FAST) program for various cases of notional watch. It was found from the USS San Jacinto survey results that enlisted and officers both preferred the alternative 3/9 watch schedule when compared to other watches that the crew members stood in the past. When comparing the predicted effectiveness while on watch, it was found that the 3/9 watch was best for four section duty, the straight fours was best for three section duty, and the 12/12 watch was best for two section duty.

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LIST OF ACRONYMS AND ABBREVIATIONS

ANSI	American National Standards Institute
API	American Petroleum Institute
BAC	Blood Alcohol Concentration
CO	Commanding Officer
CMC	Command Master Chief
CEM	Crew Endurance Management
DoD	Department of Defense
DOT	Department of Transportation
EASA	European Aviation Safety Agency
FAST	Fatigue Avoidance Scheduling Tool
FRMS	Fatigue Risk Management Systems
FAA	Federal Aviation Administration
FRSA	Federal Rail Safety Act
INSURV	Board of Inspection and Survey
NASA	National Aeronautics and Space Administration
NPS	Naval Postgraduate School
NSWW	Navy Standard Work Week
NREM	Non Rapid Eye Movement
OOD	Officer of the Deck
PHMSA	Pipeline and Hazardous Materials Safety Administration
POMS	Profile Of Mood States
PCO	Prospective Commanding Officers
PEO	Prospective Executive Officers
PVT	Psychomotor Vigilance Test
REM	Rapid Eye Movement
SAIC	Science Applications International Corporation
SEA	Senior Enlisted Academy
SAFTE	Sleep, Activity, Fatigue, and Task Effectiveness
SWO	Surface Warfare Officer
SWOS	Surface Warfare Officer School

TEST	Task Effectiveness Scheduling Tool
U.S.	United States
USAF	United States Air Force
USCG	United States Coast Guard
USN	United States Navy
VV&A	Verification, Validation and Accreditation
WRAIR	Walter Reed Army Institute of Research

EXECUTIVE SUMMARY

In recent years, "optimal" manning has been implemented on U.S. Navy surface ships where crew sizes have been reduced. This undermanning has resulted in a requirement for sailors to stand longer watches and get less sleep, making for less effective sailors while standing watch. Alternative watch schedules can be used that minimize fatigue of sailors while on watch. The USS San Jacinto (CG-56) used an alternative 3/9 watch schedule recently while on deployment.

The first objective of this study is to analyze a USS San Jacinto crew survey, which compared an alternative watch schedule to more traditional watch schedules. The second objective is to create and analyze various notional use cases of watch schedules to minimize fatigue and maximize predicted performance while on watch. The Fatigue Avoidance Scheduling Tool (FAST) utilizes the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) model to predict cognitive effectiveness based on sleep history. Crew fatigue is analyzed using the FAST program for various cases of notional watch.

The results from the USS San Jacinto survey showed that enlisted and officers both preferred the alternative 3/9 watch schedule when compared to other watches that the crew members had stood in the past. When comparing the predicted effectiveness while on watches with no shifting, it was found that the 12/12 watch was best for two section duty, the straight fours watch was best for three section duty, and the 6/18 watch was best for four section duty. For watches with shifting, it was found that the 6/12 watch shifted forward was best for three section duty, and the 3/9 watch shifted forward with no consecutive watches was best for four section duty. It was also found that shifting the watch forward is better than shifting the watch back, but not shifting the watch results in the best performance characteristics. The results from this study were summarized in a Commanding Officer's watch reference guide.

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I. INTRODUCTION

A. BACKGROUND

A recent U.S. Navy (USN) report issued by a panel of seven senior Naval officers headed by retired Vice Admiral Phillip Balisle stated, "the surface Navy is woefully undermanned." The Board of Inspection and Survey (INSURV) recently showed a ship inspection failure rate of 14% from 2005–2009 (Balisle, 2010), compared to a failure rate of approximately 3.5% just ten years earlier. In order to save money, "lean" or "optimal" manning has been implemented where crew sizes on U.S. Navy surface ships have been reduced. These efforts may have inadvertently degraded the readiness levels of today's modern warships due to severe sailor undermanning. This undermanning results in a requirement for sailors to stand longer watches and get less sleep, which makes for less effective sailors while standing watch.

Watch scheduling on ships is based upon the number of qualified crew available to stand watch. There are many different watch schedules available depending if the ship's crew are standing two, three, or four section duty. Some of the available watches are port / starboard, 5/10, 5/15, 4/8 with or without "Dog Watch" and 6/12. A typical watch will depend on operations, training and maintenance requirements, and crew availability (i.e., not sick, qualified, and able to stand watch). The combination of all of these factors makes watch scheduling different for ships of different classes, and even different among ships of the same class.

A recent Naval Postgraduate School (NPS) thesis by Lazzaretti (2008), which examined seven years of mishap rates in USN frigates, showed a relationship between manning levels and safety. The results found that the highest number of mishaps occurred in ships with the lowest manning levels. Another set of NPS theses has focused on the actual work and rest patterns of sailors while underway on ships and compared them to the Navy Standard Work Week (Haynes, 2007; Mason, 2009; Green, 2009). The sailors in these studies did not receive the required training or the allocated amount of sleep in the Navy Standard Work Week (NSWW) model while underway. The results from these four NPS theses conclude that undermanning on ships can result in an increase in mishaps and reduced sailor performance due to the fatigue from reduced sleep. This poses an operational risk to the fleet.

There have been many scientific studies over the years of sleep and sleep deprivation showing various negative behavioral outcomes in people who were deprived of sleep. Some of these negative effects were difficulty concentrating and communicating, fuzzy reasoning and slowed comprehension, decreased attention, mood changes, and reduced motivation (Angus & Heslegrave, 1985; Belenky et al., 2003; Carskadon & Dement, 1981; Dinges, Rosekind, & Neri, 1997). The effects of sleep deprivation have been compared to alcohol intoxication with hours of wakefulness equated to a blood alcohol concentration (BAC). Approximately 20–25 hours of wakefulness produced performance decrements equivalent to those observed at a BAC of 0.10% (Dawson & Reid, 1997; Lamond & Dawson, 1999). A BAC of 0.08% is the level at which a person is legally impaired in the U.S. Memory and creativity are both negatively impacted by sleep deprivation (Butcher, 2000; Stickgold, 2005; Wagner, Gais, Haider, Verleger, & Born, 2004; Walker, Brakefield, Hobson, & Stickgold, 2003). Decision-making in uncertain conditions, commonplace in military operations, is particularly vulnerable to sleep loss and this vulnerability becomes more pronounced with increased age (Killgore, Balkin, & Wesensten, 2006).

The undermanning on surface ships in the U.S. Navy has led to watch schedules that decrease sleep quantity and quality and induce fatigue in sailors. Fatigue causes judgment errors, and naval safety officials suspect that fatigue is a big culprit in the 85% of mishaps caused by human error. In addition to causing fatigue, the lean manning on ships is bad for crew morale and retention of sailors.

Lean manning on ships will soon end (Hatch, 2010) and many billets will be returned to ships. With an end to lean manning and many ships receiving more sailors to stand watch, they can switch from three section to four section duty. Alternative watch schedules such as the 3/9 can then be implemented. Standing fewer hours of watch means more opportunity for sleep for sailors, less fatigue, a more effective crew, and fewer mishaps. On a recent deployment, the Commanding Officer (CO) of the USS San

Jacinto (CG-56) decided to use an alternative watch schedule (3 on / 9 off) and, at the end of the cruise, a survey was administered to the crew to determine how well it was accepted by the crew.

B. OBJECTIVES

The first objective of this thesis is an analysis of the USS San Jacinto crew survey, which compared an alternative watch schedule to more traditional watch schedules. The survey contained both categorical and open-ended answers, which were analyzed for crew preference and the amount of sleep received by using an alternative 3/9 watch schedule while on deployment. The second objective is to create and analyze various notional use cases of watch schedules to minimize fatigue and maximize predicted performance while on watch, and create a CO's watch reference guide to be used that summarizes the results. The Fatigue Avoidance Scheduling Tool (FAST) utilizes the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) model to predict cognitive effectiveness based on sleep history. Crew fatigue is analyzed using the FAST program for various cases of notional watch schedules for comparison of predicted effectiveness levels while on watch.

This thesis can help inform future Navy policy on issues involving manning and watchstanding. This study also directly supports commanding officers of U.S. Navy by developing a CO's watch reference guide to help decide which watch schedules to apply given predicted effectiveness levels for the crew that are associated with various watch schedules.

C. SCOPE, LIMITATIONS, AND ASSUMPTIONS

One limitation of this thesis is that there is only one set of survey data comparing crew preference and sleep received by sailors on an alternative 3/9 watch schedule to more traditional watch schedules. This data set represents the population of one ship, and not the entire fleet of Navy ships and their crews. Different ships and their crews may have different preferences than the crew of the USS San Jacinto in regards to the 3/9 watch schedule. The assumptions in this thesis for the various use cases of different watch schedules will be analyzed using FAST are: people will sleep when they are scheduled, and no switching of watches will occur by the crew or Senior Watch Officer. The assumption that people will sleep when they are scheduled may not be that realistic, as there are “all hands” drills that will take place interrupting sleep. Additionally, people do swap watches occasionally on ships, which will affect their fatigue and performance levels and will differ from the predicted effectiveness levels generated from the FAST program.

D. THESIS ORGANIZATION

Chapter II contains a literature review of sleep, fatigue, ship watchstanding guidelines, and fatigue assessment models and software. Chapter III contains the methodology used in this study to analyze a set of survey data on an alternative watch schedule used by a crew on deployment, and the development of use cases for various watch schedules to be analyzed in the FAST program. Chapter IV contains the analysis of the results, while Chapter V contains the conclusions and additional recommendations for future work. References and appendices follow Chapter V.

II. LITERATURE REVIEW

This literature review provides the scientific background of sleep and fatigue, and descriptions of the software used in this thesis for the modeling of fatigue and performance prediction. Section A provides an overview of sleep, which includes factors affecting sleep quality, phases of sleep, and how performance is related to sleep. Section B reviews the literature on fatigue and how it is related to sleep and how it affects performance. Section C looks at the various ship watchstanding guidelines for the U.S. Navy and different commanders' watch guides are reviewed in Section D. The Sleep, Activity, Fatigue, and Task Effectiveness model is reviewed in Section E, which is used in the Fatigue Avoidance Scheduling Tool software (Section F). The Task Effectiveness Scheduling Tool is reviewed in Section G.

A. SLEEP

Sleep is critical for human survival and is very important for a person's health and performance. Optimal sleep, both in quantity and quality, is necessary for maximum performance and alertness. Reduced or degraded sleep can decrease or impair alertness and performance (Dinges, 1997; Maquet et al., 2000). There can be adverse effects on memory, vigilance, decision making, mood, and reaction time. Americans average 6.9 hours of sleep a night—less than the 7.5 to 8 hours sleep experts believe most people need to function at their best (Epstein & Mardon, 2006). A study of 141 mariners from eight commercial ships showed that the average sleep received in a 24 hour period while on shipboard duty was 6.6 hours. The results show that there is a fatigue problem in the U.S. maritime industry (Sanquist, Raby, Forsythe & Carvalhais, 1997). U.S. Navy sailors on deployment typically receive much less sleep than the average American and also receive less sleep than required by the Navy Standard Work Week (Green, 2009).

1. Stages of Sleep

Sleep is an active physiological process where metabolism generally slows down, and all major organs and regulatory systems continue to function. Sleep can be categorized into two distinct types: rapid eye movement (REM) sleep and non REM sleep (NREM) (National Sleep Foundation, 2006). REM sleep is associated with an extremely active brain that is often dreaming and accompanied by bursts of rapid eye movements. NREM sleep is divided into four stages, with usually less cortical activity during these stages (LeClair, 2001). NREM composes about 75% of sleep, and REM composes about 25% of sleep, as shown in Figure 1.

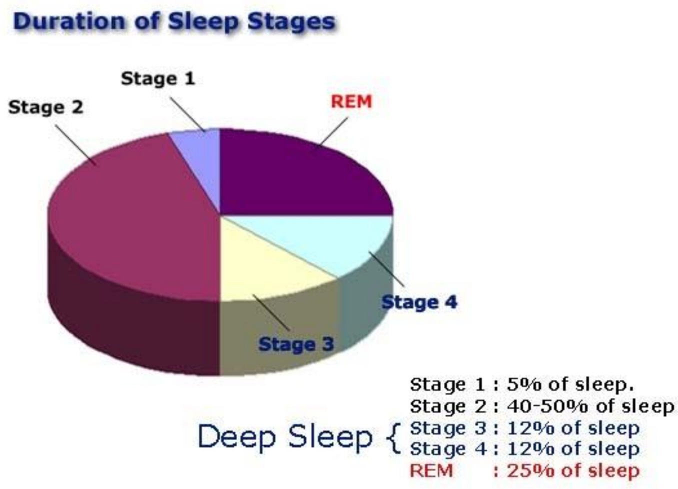

Figure 1. Duration of sleep stages (From Postawski, n.d.)

As a person goes to sleep, he or she enters Stage 1 sleep, which is a time of drowsiness or transition from being awake to falling asleep. Brain waves and muscle activity begin to slow down during this stage (National Sleep Foundation, 2006). After Stage 1 a person enters Stage 2, a period of light sleep during which eye movements stop. Brain waves become slower, the heart rate slows, and body temperature decreases. Stages 3 and 4 are considered deep sleep and are characterized by slower breathing, lower blood pressure, and lower body temperature. Sleep is deeper and it is most difficult to be awakened during these stages, with no eye movement and reduced muscle activity. If awakened during Stages 3 or 4, a person may experience "sleep inertia," which is a feeling of grogginess and disorientation for up to 10 or 15 minutes after waking (LeClair, 2001; National Sleep Foundation, 2006).

REM sleep is associated with bursts of rapid eye movement. Dreaming typically occurs during REM sleep (National Heart, Lung, and Blood Institute, 2005). The eye movement that occurs during REM sleep is considered an index of the intensity of the REM sleep (Siegel, 2001). A full cycle of REM and NREM sleep is approximate 90 minutes, with about 60 minutes of NREM followed by 30 minutes of REM sleep, which repeats four to six times per night (LeClair, 2001). A graph of the sleep cycles throughout sleep is shown in Figure 2. Throughout the night, the time spent in REM sleep increases, and the time spent in deep sleep decreases.

Figure 2. Sleep cycles throughout sleep (From Postawski, n.d.)

2. Sleep Reservoir

Obtaining less sleep than required during a 24-hour period results in acute or cumulative sleep debt. An inability to function normally following this period of sleep loss may be ameliorated by sleeping more and/or more deeply the following night (Lambert, 2005). The sleep reservoir represents the sleep-dependent process that governs the capacity to perform cognitive work. Under fully rested optimal conditions, a person has a finite maximum sleep reservoir capacity. While awake, this reservoir is depleted, whereas it is replenished when asleep (Hursh et al., 2004). Figure 3 shows a graph of the sleep reservoir balance, which is the top line in the figure. As a person sleeps (from 0 to 8 hours in the figure), his or her sleep reservoir is replenished, and is depleted throughout the day when awake. Replenishment of the sleep reservoir is determined by sleep intensity and quality. Sleep intensity is governed by the time of day (circadian process) and the current level of the sleep reservoir (sleep debt). Sleep quality is based on whether the sleep is continuous or fragmented (Hursh et al., 2004).

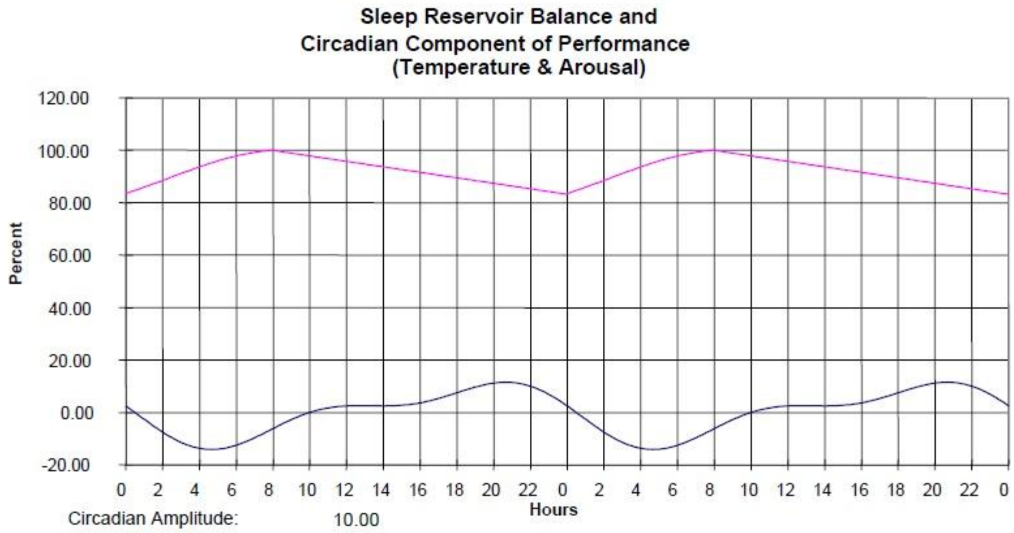

Figure 3. Sleep reservoir balance (top line) and circadian rhythm of alertness (bottom line) (From Hursh, 2003)

Acute sleep loss is when a person misses a significant portion of sleep when compared to what he or she normally gets during a 24 hour period. If a person normally gets eight hours of sleep per night, an example of acute sleep loss would be losing two or three hours of sleep. Sleep loss results in chronic excessive fatigue and sleepiness, sagging motivation for work, and poor job performance, which can lead to frustration and conflict with other workers (Naitoh, Kelly, & Englund, 1990). It can also result in reduced vigilance, slowed reaction time, poor communication, and impaired decision making (Dinges, Rosekind, & Neri, 1997). Unimpaired decision making, good communications, and increased vigilance are essential for the watchstander to stand a good watch. The sleep debt resulting from acute sleep loss can be alleviated by obtaining a greater amount of sleep than normal or increased quality of sleep during the following sleep period (Lambert, 2005).

Cumulative (or chronic) sleep loss is the result of numerous days or weeks of inadequate sleep and excessive wakefulness. Smaller amounts of sleep deprivation occur than in acute sleep loss, but there is a cumulative effect. The psychomotor vigilance test (PVT) measures the ability of an individual to detect changes within a simple visual target detection task. The test subject presses a button as soon as the light appears. The light will turn on randomly every few seconds for 5 to 10 minutes. The task assesses both the reaction time, and also determines how many times the button is not pressed when the light is on (i.e., lapses). The purpose of the PVT is to measure sustained attention, and give a numerical estimate of alertness by assessing reaction time and counting the number of lapses in attention of the tested subject (Basner & Dinges, 2011). Figure 4 shows the average PVT lapses compared to baseline test conducted for different individuals with various amounts of sleep over 14 days. The individuals who had 4 or 6 hours of sleep per night had an average higher number of lapses in the test and overall lower performance due to the cumulative sleep loss when compared to the individuals who received 8 hours of sleep per night.

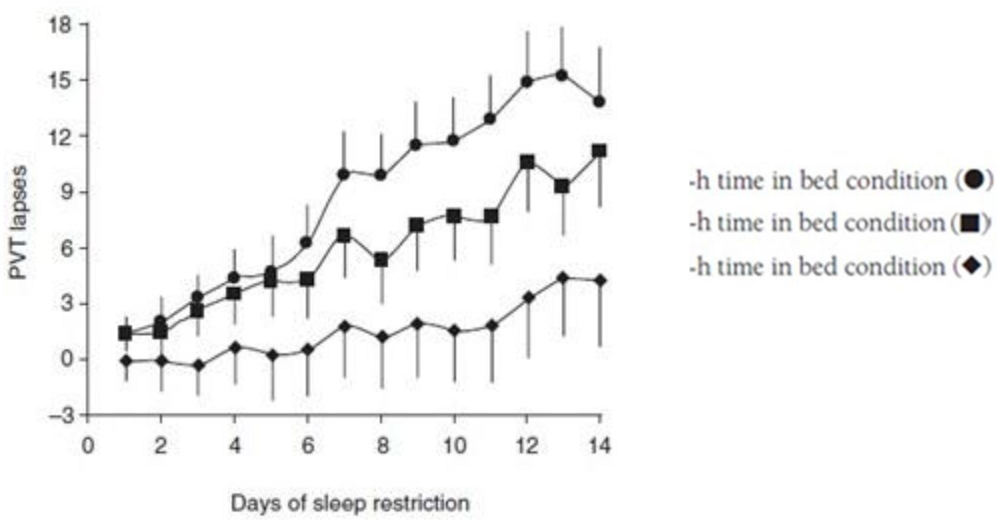

Figure 4. Changes in neurobehavioral function over 14 days of sleep restriction (From Van Dongen, Rogers, & Dinges, 2003)

The sleep reservoir depletion is due to acute or cumulative sleep loss, and replenishment is determined by sleep intensity and quality. Sleep intensity is determined by the time of day (circadian process) and the current level of the sleep reservoir. Sleep quality is determined by whether the sleep is continuous or fragmented (Hursh et al., 2004). If a person's sleep reservoir is not ultimately replenished, that person will continue to suffer poor performance, decreased alertness, and fatigue. Figure 5 shows the PVT mean speed vs. days as a function of time for various groups of people who received various amounts of sleep. After seven days, the people who received decreased sleep were allowed to sleep a full nine hours. The people who received nine hours of sleep each night had the best and most consistent performance in the test, while the people who received less sleep had increasingly worse performance each day and as their amount of sleep received each night decreased. After seven days of reduced sleep, the mean test speed for the PVT test increased for the people who received reduced amounts of sleep. In other words, reaction time was slower and response latency increased. This illustrates how people who received insufficient sleep had poor performance since their sleep reservoirs were depleted, but performance increased (although not to baseline levels) after their sleep reservoirs were replenished.

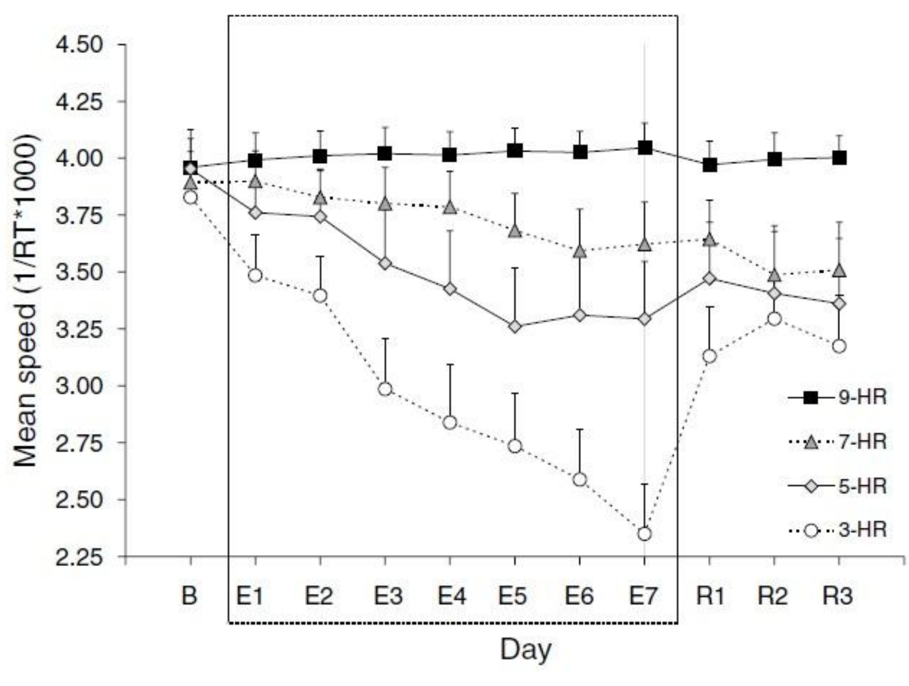

Figure 5. Mean psychomotor vigilance task speed across days as a function of time in bed (From Belenky et al., 2003)

3. Circadian Rhythm and Homeostasis Factors

The circadian rhythm refers to the cyclical changes that occur over a 24-hour period and are driven by the brain's biological "clock" (National Sleep Foundation, 2006). It governs sleep patterns, motor activity, hormonal processes, body temperature, performance, and other factors (LeClair, 2001). Figure 6 shows how the alertness level for a person typically varies throughout the day due to the circadian rhythm. There are two periods of maximum wakefulness and sleepiness during the normal 24 hour day due to the circadian rhythm. The primary and secondary peaks of alertness typically occur around 12 p.m. and 9 p.m. A major dip in alertness typically occurs in the early hours of the morning between 3 a.m. and 5 a.m., with a second dip occurring between 3 p.m. and 5 p.m. (Rosekind, Co, Gregory, & Miller, 2000).

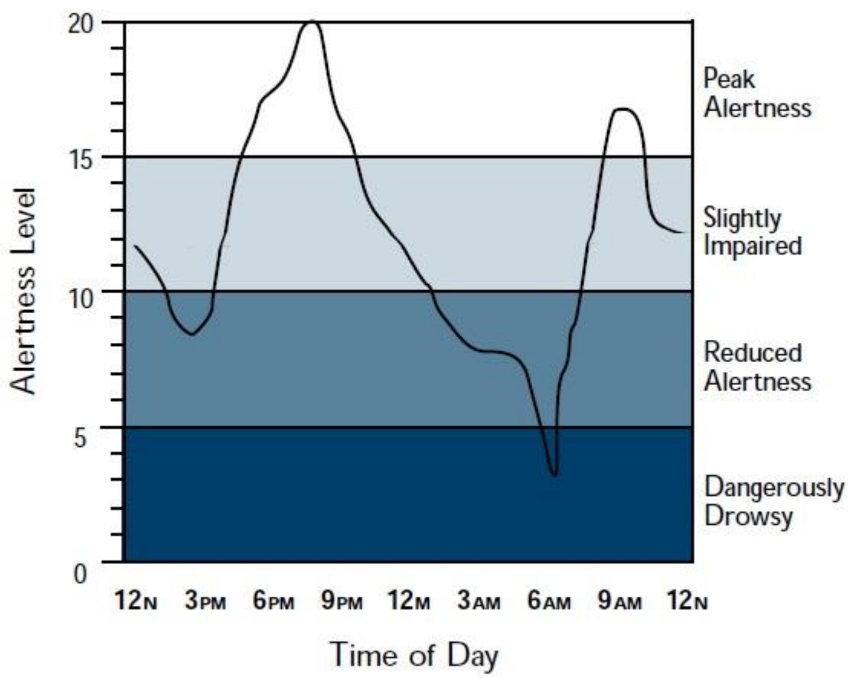

Figure 6. Daily circadian rhythm (From National Highway Traffic Safety Administration, 2007)

Homeostasis is the process by which the body maintains a "steady state" of internal conditions such as temperature, blood pressure, and the amount of sleep obtained each night. From the time we wake up, the homeostatic drive for sleep accumulates, reaching its maximum level in the late evening when most people fall asleep (National Sleep Foundation, 2006). The homeostatic process represents the drive for sleep that increases during wakefulness and decreases during sleep. When the "homeostat" increases above a certain level, sleep is triggered; when it falls below a certain level, wakefulness is invoked (Van Dongen & Dinges, 2000).

In general, the homeostatic system tends to make a person sleepier with continuing wakefulness, regardless of whether it is night or day, while the circadian system tends to keep a person awake as long as there is daylight, prompting them to sleep as soon as it becomes dark. Because of the complexity of this interaction, it is generally agreed that sleep quality and restfulness are best when the sleep schedule is regularly synchronized to the internal circadian rhythms and that of the external light-dark cycle — that is when we go to bed at night and wake up in the morning at around the same (National Sleep Foundation, 2006).

B. FATIGUE

Fatigue is not just feeling physically tired; it can also refer to a state of impaired alertness, reduced attentiveness, and degraded mental and physical performance. Being fatigued also includes having reduced motor coordination and slower reaction time. When we are fatigued, there is a loss of environmental awareness, impairment of cognitive/logical reasoning skills, poor judgment and diminished ability to communicate and/or process communications and information (Sirois, 2009). Fatigue occurs frequently in night shift workers since they are working when their bodies want them to sleep. The fatigue experienced by night shift workers can be dangerous. Major industrial accidents—such as the Three Mile Island and Chernobyl nuclear power plant accidents and the Exxon Valdez oil spill—have been caused, in part, by mistakes made by overly tired workers on the night shift or an extended shift (National Heart, Lung, and Blood Institute, 2005). A review of incidents in the commercial power industry and of the National Aeronautics and Space Administration (NASA) space shuttle program has shown many other examples of human fatigue as the cause of these incidents. Times between 1 a.m. and 8 a.m. constitute a time span in the 24-hour day when human medical and performance catastrophes are far more likely to occur (Mitler et al., 1988).

1. Fatigue and Performance Impairment

Operational effectiveness increasingly relies on complex mental processes that are highly susceptible to the impact of fatigue. Some of the effects of fatigue on performance include:

- Reduced attention
- Communication difficulties
- Mood changes
- Inability to concentrate
- Increasing omissions and carelessness
- Slowness in perception
- Decreased vigilance
- Slowed comprehension and learning
- Encoding / decoding difficulties
- Hallucinations
- Muddled thinking
- Faulty short-term memory
- Slow and uneven responsiveness

(From Murphy, 2002)

A previous study was conducted where soldiers were kept up for 90 hours of continuous activity. It was found that after three nights without sleep, performance on tasks deteriorates by nearly 50%, and in some cases, as low as 35% of baseline values, at which point soldiers were judged to be militarily ineffective (Krueger, 1989). There is scientific evidence that suggests when we are tired or fatigued, our ability to perform the simplest of tasks is impaired to the same level as if we were legally intoxicated (Dawson & Reid, 1997). Figure 7 shows the mean relative performance vs. hours of wakefulness and the equivalent percentage of blood alcohol concentration. After 17 hours of sustained wakefulness, cognitive psychomotor performance decreased to a level equivalent to the performance impairment observed at a blood alcohol concentration of 0.05%. After 24 hours of sustained wakefulness, cognitive psychomotor performance decreased to a level equivalent to the performance observed at a BAC of roughly 0.1% (Dawson & Reid, 1997).

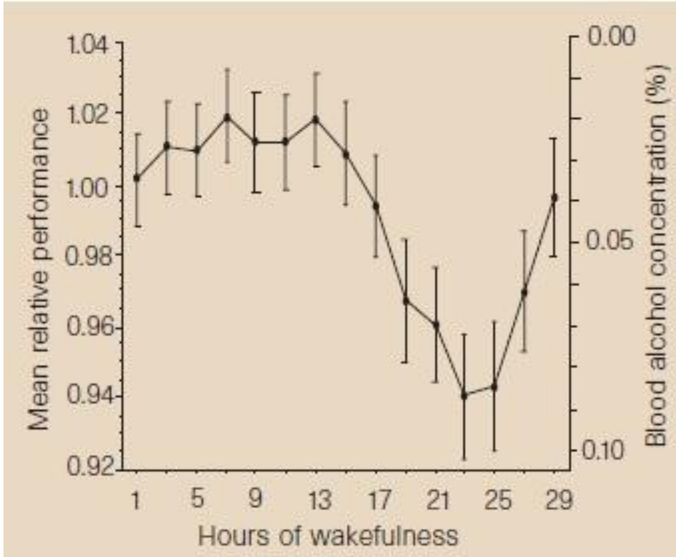

Figure 7. Performance in the sustained wakefulness condition expressed as mean relative performance and the percentage of blood alcohol concentration equivalent (From Dawson & Reid, 1997)

2. Fatigue and Risk Management

Fatigue Risk Management Systems (FRMS) integrate facts and scientific knowledge to understand fatigue and how to mitigate the risks it poses to people while at work. The pace of adoption of FRMS in various organizations has been accelerating. Just in 2008 to 2009 (Moore-Ede, 2009):

- The European Aviation Safety Agency (EASA) has made having an FRMS a requirement for operating in Europe.
- The American Petroleum Institute (API) developed an American National Standards Institute (ANSI) standards document that makes FRMS the operating requirement for managing employee fatigue in the petrochemical industry.
- The Federal Rail Safety Act (FRSA) mandated that the U.S. railroads have fatigue management plans.
- The U.S. Department of Transportation (DOT) Pipeline and Hazardous Materials Safety Administration (PHMSA) proposed rule changes for natural gas pipeline control rooms that will include fatigue risk management.

President Obama recently signed into law H.R. 5900 – the Airline Safety and Federal Aviation Administration (FAA) Extension Act of 2010 (H.R. 5900, 2010). This law required all U.S. registered airlines that operate flights based on published schedules to develop a FAA acceptable Fatigue Risk Management Plan by October 31, 2010. Numerous entities outside of the U.S. Navy are implementing fatigue risk management systems and getting more serious about preventing fatigue when scheduling their employees for work.

C. SHIP WATCHSTANDING GUIDELINES

There are surprisingly few references available for USN ship watchstanding guidelines regarding watch schedules. The Watch Officer's Guide states that the Officer of the Deck (OOD) should be physically prepared, fresh, and well rested before standing the watch (Stavridis, 2000). This book is an excellent guide on watchstanding, but does not have any information on watch schedules. OPNAV Instruction 3120.32C states:

> LENGTH OF WATCH AND ROTATION. The length of time for continuous watches is normally four hours. However, the length of assignment to a watch should be based on the conditions under which the watch will be stood. The officer in charge of a watch station shall ensure that watchstanders are rotated frequently enough to stand an effective watch.

The standard watches for Navy ships / units are shown in Table 1.

Hours	Watch
0000 – 0400	Mid Watch
0400 – 0800	Morning Watch
0800 – 1200	Forenoon Watch
1200 – 1600	Afternoon Watch
1600 – 1800	First Dog Watch
1800 – 2000	Second Dog Watch
2000 – 2400	Evening Watch

Table 1. Standard U.S. Navy watch sections

In reality, few ships follow the standard Navy watches, and instead use watch rotations depending on several factors, such as how many people are qualified and available to stand watch, training and maintenance requirements, and the current operations that are taking place. The number of people qualified and available to stand watch will determine if there are two, three, or four duty sections. The number of duty sections will determine which watches are available, and are outlined below for the various number of duty sections.

There are generally two types of watch schedules: fixed shift and rotating shift. For fixed shift, the sailor always stands watch during the same shift each day. For rotating shift, the sailor rotates from one watch shift to another at one specific interval. A shift can be rotated either forward ("clockwise") or backwards ("counterclockwise") (Miller, 2006). Miller found that in shiftwork scheduling the overall optimal number of crews was four, but this was because in the civilian sector overtime was required to be paid for work performed beyond 40 hours per week. In the military, this is not the case. For ship watch scheduling in the Navy, the major factor for watch scheduling is usually the number of able and qualified sailors that can stand watch in a division.

1. Two Section Watches

Table 2 shows the watches available for two section duty for both four hour and six hour dogged watches. A dogged watch splits a watch into two shorter watches so there are an odd number of watches each day. Doing so necessitates crew members to have a different watch schedule each day (Bearden, 1990). Sometimes the watch team stands the same watch for one or two weeks, and shifts on a specific day, such as Sunday. The switching of the watch can either be backwards or forward. Table 3 shows the watches available for two section duty for both four hour and six hour shifted forward on day 3.

Two section standard (4 hr) dogged watch

Time	Day 1	Day 2	Day 3
0000 – 0400	Team 1	Team 2	Team 1
0400 – 0800	Team 2	Team 1	Team 2
0800 – 1200	Team 1	Team 2	Team 1
1200 – 1600	Team 2	Team 1	Team 2
1600 – 1800	Team 1	Team 2	Team 1
1800 – 2000	Team 2	Team 1	Team 2
2000 – 2400	Team 1	Team 2	Team 1

Two section port/starboard (6 hr) dogged watch

Time	Day 1	Day 2	Day 3
0000 – 0600	Team 1	Team 2	Team 1
0600 – 1200	Team 2	Team 1	Team 2
1200 – 1800	Team 1	Team 2	Team 1
1800 – 2100	Team 2	Team 1	Team 2
2100 – 2400	Team 1	Team 2	Team 1

Table 2. Two section dogged watches

Two section standard (4 hr) shifted watch

Time	Day 1	Day 2	Day 3	Day 4
0000 – 0400	Team 1	Team 1	Team 2	Team 2
0400 – 0800	Team 2	Team 2	Team 1	Team 1
0800 – 1200	Team 1	Team 1	Team 2	Team 2
1200 – 1600	Team 2	Team 2	Team 1	Team 1
1600 – 1800	Team 1	Team 1	Team 2	Team 2
1800 – 2400	Team 2	Team 2	Team 1	Team 1

Two section port/starboard (6 hr) shifted watch

Time	Day 1	Day 2	Day 3	Day 4
0000 – 0600	Team 1	Team 1	Team 2	Team 2
0600 – 1200	Team 2	Team 2	Team 1	Team 1
1200 – 1800	Team 1	Team 1	Team 2	Team 2
1800 – 2400	Team 2	Team 2	Team 1	Team 1

Table 3. Two section shifted watches

2. Three Section Watches

Some of the more typical three section duty watches are the 5/10 ("five and dime") and 4/8 (with and without dogged watch). Table 4 shows the 5/10, and the 4/8 without dogging over a three day period. The 5/10 watchstanders will stand a different watch each day, equating to a 30 hour day, while the 4/8 watchstanders are on a 24 hour day and will stand the same watch unless the watch is dogged, or shifted on a specific day.

Three section standard 5/10 watch

Time	Day 1	Day 2	Day 3
0100	Team 1	Team 2	Team 1
0200	Team 1	Team 3	Team 1
0300	Team 1	Team 3	Team 2
0400	Team 1	Team 3	Team 2
0500	Team 1	Team 3	Team 2
0600	Team 2	Team 3	Team 2
0700	Team 2	Team 1	Team 2
0800	Team 2	Team 1	Team 3
0900	Team 2	Team 1	Team 3
1000	Team 2	Team 1	Team 3
1100	Team 3	Team 1	Team 3
1200	Team 3	Team 2	Team 3
1300	Team 3	Team 2	Team 1
1400	Team 3	Team 2	Team 1
1500	Team 3	Team 2	Team 1
1600	Team 1	Team 2	Team 1
1700	Team 1	Team 3	Team 1
1800	Team 1	Team 3	Team 2
1900	Team 1	Team 3	Team 2
2000	Team 1	Team 3	Team 2
2100	Team 2	Team 3	Team 2
2200	Team 2	Team 1	Team 2
2300	Team 2	Team 1	Team 3
2400	Team 2	Team 1	Team 3

Three section 4/8 watch (no dogging)

Time	Day 1	Day 2	Day 3
0100	Team 1	Team 1	Team 1
0200	Team 1	Team 1	Team 1
0300	Team 1	Team 1	Team 1
0400	Team 1	Team 1	Team 1
0500	Team 2	Team 2	Team 2
0600	Team 2	Team 2	Team 2
0700	Team 2	Team 2	Team 2
0800	Team 2	Team 2	Team 2
0900	Team 3	Team 3	Team 3
1000	Team 3	Team 3	Team 3
1100	Team 3	Team 3	Team 3
1200	Team 3	Team 3	Team 3
1300	Team 1	Team 1	Team 1
1400	Team 1	Team 1	Team 1
1500	Team 1	Team 1	Team 1
1600	Team 1	Team 1	Team 1
1700	Team 2	Team 2	Team 2
1800	Team 2	Team 2	Team 2
1900	Team 2	Team 2	Team 2
2000	Team 2	Team 2	Team 2
2100	Team 3	Team 3	Team 3
2200	Team 3	Team 3	Team 3
2300	Team 3	Team 3	Team 3
2400	Team 3	Team 3	Team 3

Table 4. Common three section watches

3. Four Section Watches

Some of the more typical four section watches are the 6/18, which equates to a 24 hour day, and 5/15, which equates to a 20-hour day, and are shown in Table 5. The 6/18 watchstanders will stand the same watch unless the watch is dogged, or shifted forward or backwards on a specific day, whereas the 5/15 watchstanders stand watch at different times each day.

Four section standard 5/15 watch

Time	Day 1	Day 2	Day 3
0100	Team 1	Team 1	Team 2
0200	Team 1	Team 2	Team 2
0300	Team 1	Team 2	Team 3
0400	Team 1	Team 2	Team 3
0500	Team 1	Team 2	Team 3
0600	Team 2	Team 2	Team 3
0700	Team 2	Team 3	Team 3
0800	Team 2	Team 3	Team 4
0900	Team 2	Team 3	Team 4
1000	Team 2	Team 3	Team 4
1100	Team 3	Team 3	Team 4
1200	Team 3	Team 4	Team 4
1300	Team 3	Team 4	Team 1
1400	Team 3	Team 4	Team 1
1500	Team 3	Team 4	Team 1
1600	Team 4	Team 4	Team 1
1700	Team 4	Team 1	Team 1
1800	Team 4	Team 1	Team 2
1900	Team 4	Team 1	Team 2
2000	Team 4	Team 1	Team 2
2100	Team 1	Team 1	Team 2
2200	Team 1	Team 2	Team 2
2300	Team 1	Team 2	Team 3
2400	Team 1	Team 2	Team 3

Four section 6/18 watch (no dogging)

Time	Day 1	Day 2	Day 3
0100	Team 1	Team 1	Team 1
0200	Team 1	Team 1	Team 1
0300	Team 1	Team 1	Team 1
0400	Team 1	Team 1	Team 1
0500	Team 1	Team 1	Team 1
0600	Team 1	Team 1	Team 1
0700	Team 2	Team 2	Team 2
0800	Team 2	Team 2	Team 2
0900	Team 2	Team 2	Team 2
1000	Team 2	Team 2	Team 2
1100	Team 2	Team 2	Team 2
1200	Team 2	Team 2	Team 2
1300	Team 3	Team 3	Team 3
1400	Team 3	Team 3	Team 3
1500	Team 3	Team 3	Team 3
1600	Team 3	Team 3	Team 3
1700	Team 3	Team 3	Team 3
1800	Team 3	Team 3	Team 3
1900	Team 4	Team 4	Team 4
2000	Team 4	Team 4	Team 4
2100	Team 4	Team 4	Team 4
2200	Team 4	Team 4	Team 4
2300	Team 4	Team 4	Team 4
2400	Team 4	Team 4	Team 4

Table 5. Common four section watches

4. Alternative Watches

The Canadian Navy conducted a study of alternative watch schedules. Table 6 shows the alternative watch schedules evaluated, which are the “8-4-4-8” for two section duty, and both the “straight eights” and “straight fours” for three section duty

Table 6. Canadian Navy alternative watch schedules (From Paul, Hursh, & Miller, 2010)

Two section 8-4-4-8 watch

Time	Work	Sleep
0100	Team 2	Team 1
0200	Team 2	Team 1
0300	Team 2	Team 1
0400	Team 2	
0500	Team 1	
0600	Team 1	Team 2
0700	Team 1	Team 2
0800	Team 1	Team 2
0900	Team 1	Team 2
1000	Team 1	Team 2
1100	Team 1	Team 2
1200	Team 1	
1300	Team 2	
1400	Team 2	
1500	Team 2	
1600	Team 2	
1700	Team 1	
1800	Team 1	
1900	Team 1	
2000	Team 1	
2100	Team 2	
2200	Team 2	Team 1
2300	Team 2	Team 1
2400	Team 2	Team 1

Three section straight eights

Time	Work	Sleep
0100	Team 3	Team 1
0200	Team 3	Team 1
0300	Team 3	Team 2
0400	Team 3	Team 2
0500	Team 1	Team 2
0600	Team 1	Team 2
0700	Team 1	Team 2
0800	Team 1	Team 2
0900	Team 1	Team 2
1000	Team 1	Team 2
1100	Team 1	Team 3
1200	Team 1	Team 3
1300	Team 2	Team 3
1400	Team 2	Team 3
1500	Team 2	Team 3
1600	Team 2	Team 3
1700	Team 2	Team 3
1800	Team 2	Team 3
1900	Team 2	Team 1
2000	Team 2	Team 1
2100	Team 3	Team 1
2200	Team 3	Team 1
2300	Team 3	Team 1
2400	Team 3	Team 1

Three section straight fours

Time	Work	Sleep	
0100	Team 1		Team 2
0200	Team 1	Team 3	Team 2
0300	Team 1	Team 3	Team 2
0400	Team 1	Team 3	
0500	Team 2	Team 3	
0600	Team 2	Team 3	
0700	Team 2	Team 3	
0800	Team 2		
0900	Team 3		
1000	Team 3		
1100	Team 3		
1200	Team 3		
1300	Team 1		
1400	Team 1		
1500	Team 1		
1600	Team 1		
1700	Team 2		
1800	Team 2	Team 1	
1900	Team 2	Team 1	
2000	Team 2	Team 1	
2100	Team 3	Team 1	
2200	Team 3	Team 1	Team 2
2300	Team 3	Team 1	Team 2
2400	Team 3		Team 2

An alternative watch schedule that was used in practice on the USS Lake Erie was the Blue and Gold watchstanding sections, giving each section 12 hours of duty, and 12 hours off, per day, changing at noon and midnight. The Blue/Gold sections would switch every month or after a port call (Capello, 2000). This schedule allows the watch section to work together and build skills as a team while on watch, and also allows plenty of downtime and sleep. The commanding officer reported that the Blue/Gold watch was extremely effective and well-liked by the crew. The 3 on / 9 off was used on the USS San Jacinto while on deployment in 2010.

D. COMMANDER'S WATCH GUIDES

There have been numerous watchstanding guides created by various government agencies both in the U.S. and abroad. These guides attempt to inform commanding officers and unit commanders about stress, fatigue, sleep deprivation, and the associated risk and problems that come from lack of sleep while on watch. They also give recommendations to the commanders about how to reduce these risks and provides tools to construct watch schedules or mission plans for their unit.

The Leader's Guide to Crew Endurance (53 pages) was produced by the U.S. Army provides an overview of stress and fatigue, sleep deprivation, work schedules and the body clock, and information on how to manage risk for crew endurance and related hazards. It states that a comprehensive crew-rest program must involve all personnel, equipment, and policies that impact mission accomplishment and safety (Comperatore, Caldwell & Caldwell, 1997). The program has several levels: the individual level, the unit level, and the material level. The individual level is implemented by the individual soldier, but this level is less amenable to adjustment or modification than the unit or material level elements. This level includes a sleep management plan, a daylight exposure management plan, a living quarters plan, and an environmental management plan. The unit level includes coordination of unit activities involving groups of schedules, but must be scheduled after consideration of individual level schedules. The material level involves work schedules and activities associated with the equipment used to accomplish mission objectives, such as aircraft refueling or maintenance schedules

(Comperatore, Caldwell & Caldwell, 1997). Figure 8 shows the various levels with examples and it illustrates how they all revolve around mission requirements.

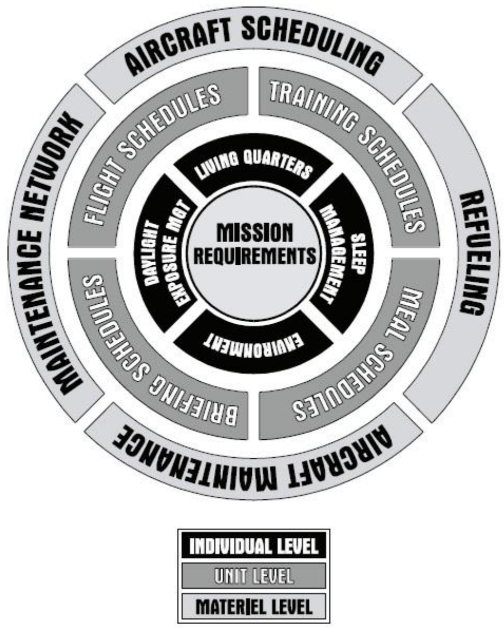

Figure 8. U.S. Army crew rest model (From Comperatore, Caldwell & Caldwell, 1997)

The Fatigue Management Guide for Canadian Pilots (33 pages) was produced by the Canadian government to be used by marine pilots in a fatigue management education workshop (Rhodes & Gil, 2003). The guide covers a review of sleep fundamentals such as sleep stages, REM and NREM sleep, the biological clock, sleep quality and quantity, and sleep disorders. It then asks questions to determine if the reader is a morning or evening person and has a score sheet to check the fatigue level of a person. It discusses the effects of irregular work shifts, causes and signs of fatigue, and various coping strategies to receive a higher quality and quantity of sleep and fight fatigue.

The United States Coast Guard (USCG) Instruction (23 pages) on Crew Endurance Management (CEM) creates a program to identify and control endurance risk for personnel conducting cutter, boat, aviation, marine inspection and pollution response, security, and command and control operations and activities (United States Coast Guard, 2006). The instruction starts with a section on the background, which states that in excess of 70% of Coast Guard members exhibited signs of compromised endurance and confirmed that fatigue contributed to mishaps. The risk factors are outlined, and an outline is given to address these risks with the CEM process. Commanding officers are directed to establish a working group and implement the CEM process.

Many of these guides are lengthy, and it is questionable if they are actually used in the field due to their length. Many commanding officers do not have the time or inclination to read a long guide. A short and concise watch guide may be more likely to be used when deciding watch schedules and mission planning.

E. SLEEP, ACTIVITY, FATIGUE, AND TASK EFFECTIVENESS MODEL

The Department of Defense (DoD) has long pursued applied research concerning fatigue in sustained and continuous military operations. Research teams were responsible for investigating fatigue related impairment of cognitive readiness "for developing countermeasures to fatigue, and for providing guidance to the Services in the management of fatigue" (Hursh et al., 2004). The Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) model is part of the result of this research.

1. Overview

The 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 three-process model of human cognitive effectiveness (Hursh, 2003). It is applied to hypothetical or prospective work / sleep schedules in order to identify potential performance problems, and to optimize operational planning and management (Hursh et al., 2004).

Figure 9 shows a schematic of the SAFTE model. The core of the model is the sleep reservoir, which represents the sleep-dependent processes that govern the capacity to perform cognitive work. While a person is awake, the sleep reservoir "contents" are depleted, and replenished while asleep. The replenishment is determined both by sleep intensity and sleep quality. Sleep intensity is, in turn, governed by both the time of day (circadian processes) and the current level of the reservoir (sleep debt). Sleep quality is modeled based on whether it is continual or fragmented. Performance effectiveness is the output of the modeled system. The level of effectiveness is simultaneously modulated by time of day (circadian) effects and the level of the sleep reservoir. Transient post sleep decay of performance is represented by the term in the model, inertia (Hursh et al., 2004).

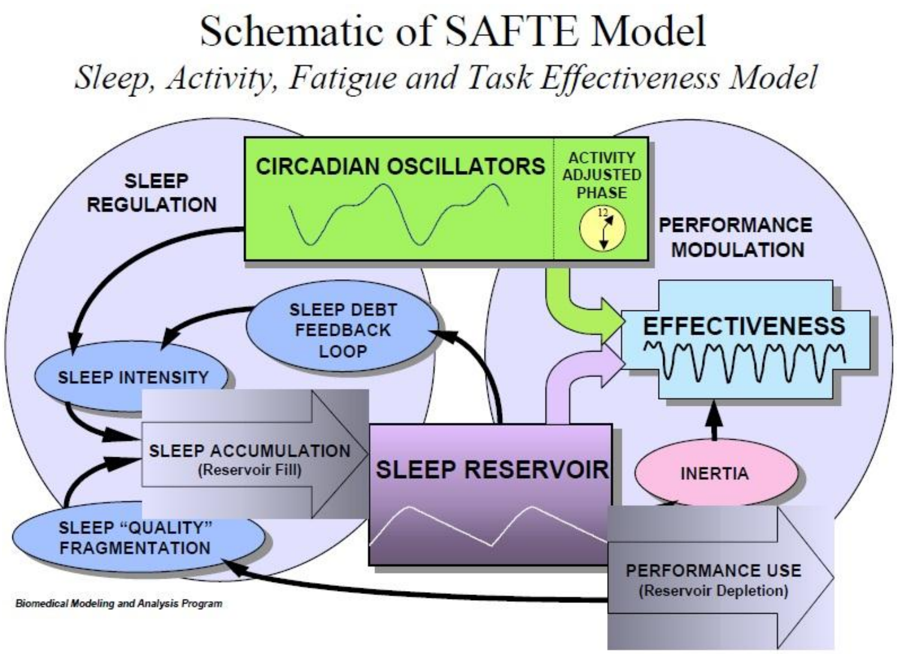

Figure 9. Schematic of SAFTE simulation model (From Hursh, 2003)

The SAFTE Model was elaborated with a process that modulates the sleep reservoir capacity during chronic sleep restriction to account for findings from recent chronic sleep restriction studies, which show slower than expected rebound of performance following recovery sleep. The SAFTE Model has also been enhanced to account for circadian shifts due to transmeridian crossings vs. shift work changes (Hursh et al., 2004).

2. Model Validation

SAFTE has been validated against group mean data from a Canadian laboratory that were not used in the model's development (Hursh, 2003). Additional laboratory and field validation studies are underway and the model has begun the USAF Verification, Validation and Accreditation (VV&A) process (Hursh, 2003) Figure 10 shows the predicted effectiveness from the SAFTE model compared to various measures of effectiveness from previous sleep deprivation studies. The SAFTE model prediction closely follows the actual data collected from the sleep deprivation studies.

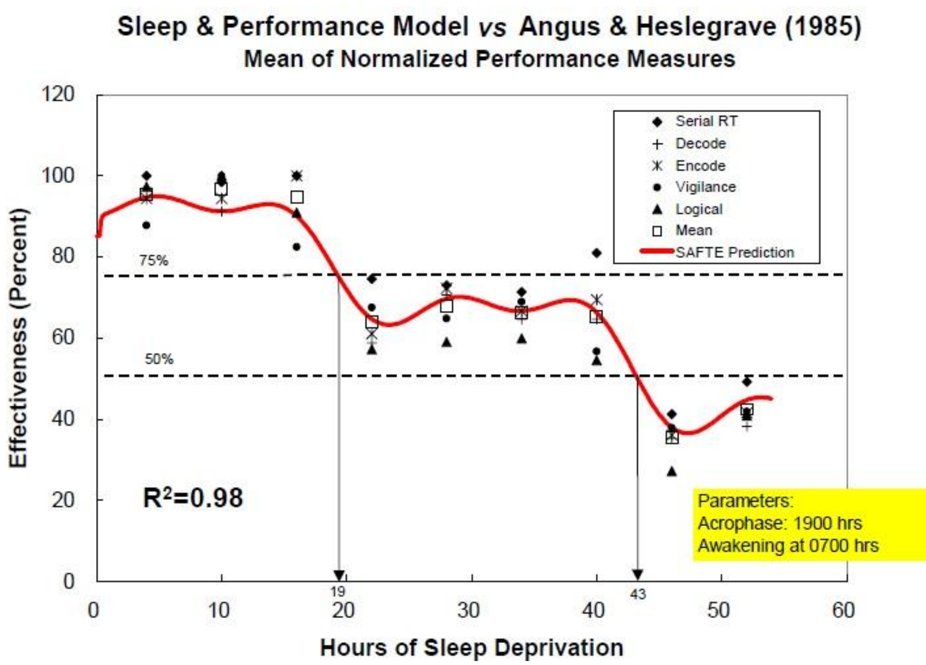

Figure 10. SAFTE sleep and performance model vs. actual performance (From Hursh, 2003)

Figure 11 shows a study conducted by the Walter Reed Army Institute of Research (WRAIR) for the mean psychomotor vigilance task speed as a percent of baseline as a function of time in bed for subjects receiving various hours of sleep. The SAFTE model prediction shows as a solid red line, closely mirrors the test results for all scenarios of sleep deprivation. In 2003, the DoD sponsored a comparison of six fatigue models from around the world. All models attempted to predict the results from four different scenarios. The SAFTE model had less error than any of the other models tested, and is now accepted by the U.S. DoD as the common warfighter fatigue model (Hursh, 2003).

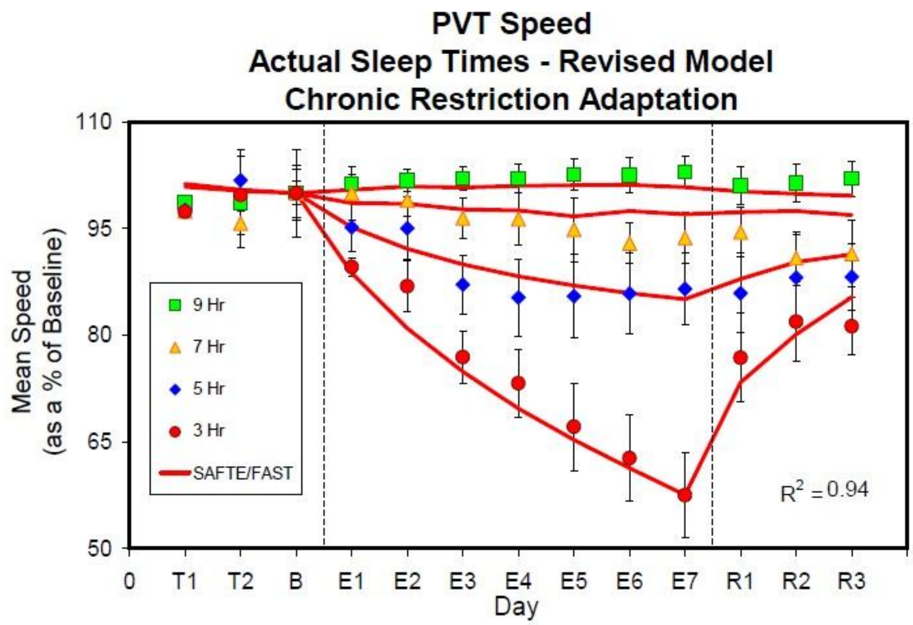

Figure 11. SAFTE model vs. mean PVT speed (From Hursh, 2003)

3. Model Limitations

George Box said "All models are wrong, but some are useful" (Box, Hunter, & Hunter, 1978). The SAFTE model is no exception, and has its shortcomings. Two major limitations are that the model does not provide an estimate of group variance about the average performance prediction and it does not incorporate any individual difference parameters, such as age, morningness / eveningness preference, or sleep requirement for full performance (Hursh et al., 2004). If the SAFTE model is to be used for prediction of average group performance or for design of a generic work schedule to be used, then the individual characteristics may be relatively unimportant. For these applications, ordinal predictions are sufficient to decide which of several alternative schedules is best or to decide if average performance at some future time is expected to be at an acceptable level (Hursh et al., 2004). The U.S. Air Force (USAF) contracted with Science Applications International Corporation (SAIC) to develop a software application of the SAFTE model, and the end result was the Fatigue Avoidance Scheduling Tool (FAST).

F. FATIGUE AVOIDANCE SCHEDULING TOOL

FAST is a fatigue assessment tool based on the SAFTE model, which was developed for the U.S. Air Force and U.S. Army (Hursh, 2003). The program contains an interface that allows a user to use actual sleep data or predicted sleep data to produce predictions of the cognitive effectiveness of an individual. The predictions may be displayed in tabular, graphical, or tabular and graphical format. The interface may also represent the effectiveness of a user based on the actual or predicted sleep data in conjunction with an actual or predicted work schedule or pattern (Hursh, 2005).

1. Overview

FAST allows the user to input past and future work and sleep schedules in half hour increments. A time period from six hours up to 30 days can be selected to view the effect of the sleep / work schedule on percent effectiveness. Additionally, the percent effectiveness is correlated to the blood alcohol content equivalent on the right hand vertical axis. Figure 12 shows a screenshot of the FAST program. Various outputs are estimates of percent predicted effectiveness and BAC equivalent, the sleep reservoir, and acrophase (the time at which the peak of the circadian rhythm occurs). The upper portion of the graph is shaded green to represent a safe zone for a predicted effectiveness of greater than 90%. The middle portion is between 65% and 90% effectiveness, which represents a caution zone. Predicted effectiveness less than 65% effectiveness is shaded red to represent a danger zone.

FAST can be used during accident investigations to evaluate the likelihood that fatigue was major factor in causing an accident. This requires the work schedule and sleep history information. It can also be used for work schedule evaluation and for improving the work and sleep scheduling based on predicted changes in performance (Hursh, 2003). Given a work and sleep schedule, one can get a forecast of future task effectiveness.

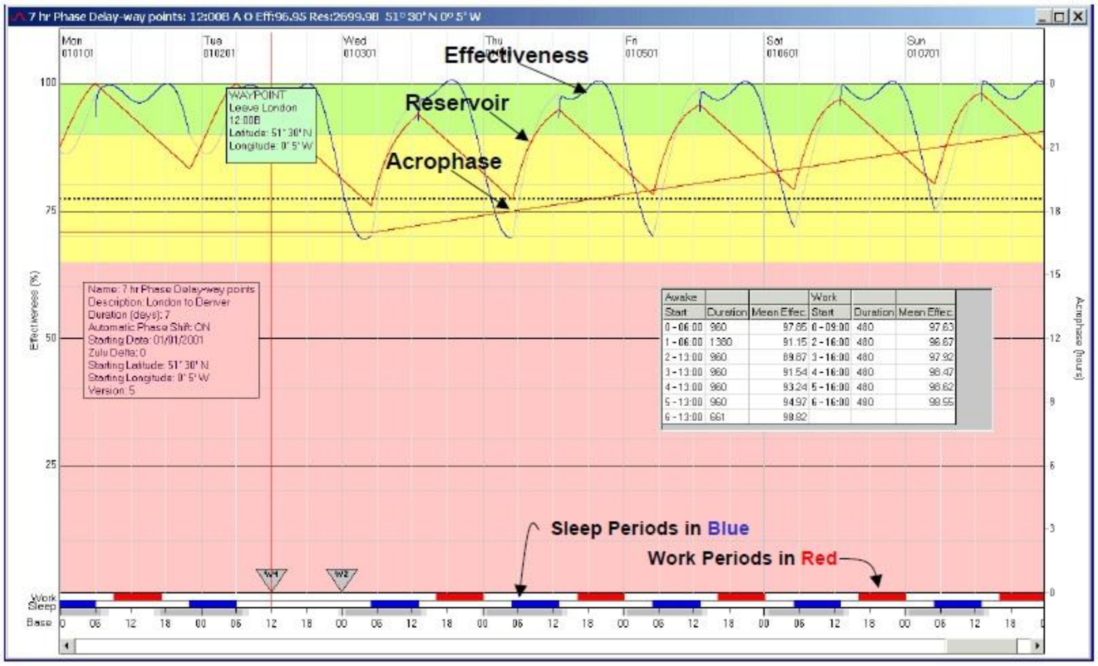

Figure 12. FAST screenshot (From Hursh, 2003)

2. Limitations

Since FAST is based upon the SAFTE model, the limitations for FAST include all of those outlined in Section E describing the limitations for the SAFTE model. Additionally, the FAST program allows the user to pick from four different qualities of sleep: excellent, good, fair, and poor:

- Excellent: 0 interruptions per hour
- Good: 1-2 interruptions per hour
- Fair: 3-5 interruptions per hour
- Poor: 6 or more interruptions per hour

These values are equated to 60, 50, 40, and 30 minutes of effective sleep per hour (Tvaryanas & Miller, 2010). The quality of sleep picked for the analysis in the program will affect the performance effectiveness. Different people can have different qualities of sleep for the same conditions. Sea state and machinery noise can affect individuals differently. In addition the quality of sleep is picked for the entire analysis of sleep and wake cycles. This selection is not accurate since a person's sleep quality may sleep excellent on one night and fair on another night. Another limitation is that sleep quality may be affected by caffeine or sleep aids, which is not reflected in the FAST program.

G. TASK EFFECTIVENESS SCHEDULING TOOL

The Task Effectiveness Scheduling Tool (TEST) is a modest mixed integer program that assigns persons to wake-sleep cycles and variable duty periods in an attempt to provide coverage of some continuous system function using the minimum quantity of personnel, while simultaneously ensuring individuals exceed an a priori predicted task effectiveness criterion during duty periods. The program then ensures that the temporal scheduling of duty periods maximizes average predicted task effectiveness over a 24-hour period (Tvaryanas & Miller, 2010).

The number of workers on duty at any particular time is set to one, and the predicted task effectiveness output from the FAST program is constrained to be greater than or equal to a requirement for each time period. The number of shifts is minimized to cover all work periods, which yields the optimal manpower solution. TEST then looks for the best arrangement of duty periods given the minimum number of workers. Solving this secondary problem yields a constrained (in terms of manpower) optimal solution for average task effectiveness. The average predicted task effectiveness is maximized for the minimum number of individuals (Tvaryanas & Miller, 2010).

The advantage for the TEST program is that it allows organizational planners to import data generated from FAST simulations into an analytical mode, which optimizes staffing and shit scheduling. Optimal staffing and shift scheduling becomes less elusive and a more deterministic process (Tvaryanas & Miller, 2010). One of the weaknesses of the TEST is that while the FAST simulation was run for a 30 day period, only the predicted task effectiveness on the thirtieth day of the simulation is recorded into the input matrix for the TEST program. Thus, the predicted effectiveness is used only for the last day of the test period, and not over the entire 30 days. Additionally, there was not an analysis of various work schedules.

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III. METHODOLOGY

The first objective of this thesis is to analyze survey data from the USS San Jacinto crew comparing an alternative watch schedule to more traditional watch schedules. The second objective is to create and analyze various notional use cases of watch schedules in the FAST program to minimize fatigue and maximize predicted performance while on watch, and create a CO's watch reference guide for use by commanding officers that summarizes the results. This chapter describes the methodology used to achieve these objectives. Section A describes the San Jacinto survey data and questions asked of the crew regarding an alternative watch schedule. Section B covers various notional watch schedules for two, three, and four section watch sections, which were analyzed in the FAST program.

A. SAN JACINTO SURVEY DATA SET

While on deployment in 2010, CAPT Cordle, the commanding officer of the USS San Jacinto (CG 56), implemented a new watch standing rotation that was 3 hours on / 9 hours off / 3 hours on / 9 hours off and was maintained for approximately five months. The original rotation was 3 hours on / 3 hours off / 3 hours on / 15 hours off. This lasted about a month and was changed based on feedback from the crew. The watch was rotated every two weeks with each watch shifting back one section. Rotation occurred on Sundays to ease the transition day. At the end of the deployment, a survey was given to the crew that gauged the amount of sleep received on the 3/9 watch, and asked how sailors liked the 3/9 watch when compared to other watches.

One hundred and twelve members of the crew responded to the survey. Five people answered no to question 2: "Have you stood watch prior to this deployment?" and three people answered no to question 3: "Did you work the current 3/9 hour watch rotation?" Data from these eight individuals were removed from the data set, since these people did not stand the watch or had not stood watch prior to this deployment, so had no basis for comparison. The resulting data set had 104 respondent's records, which were composed of 92 enlisted and 12 officers.

1. Closed-Ended Questions

There were nine closed-ended survey questions:

Question 1: Please indicate your rank or rate.

Question 2: Have you stood watch underway prior to this deployment (Check One):

☐ Yes

☐ No If No, please stop and turn in the survey materials now. Thank you for your participation.

Question 3: Did you work the current 3/9 hour watch rotation? A 3/9 watch rotation is a four section watch in which you stand watch for 3 hrs and then have 9 hrs off watch.

☐ Yes

☐ No If No, please stop and turn in the survey materials now. Thank you for your participation.

Question 4: Types of other watches I have stood (Check all that apply):

☐ 5/10 (five and dime)

☐ 5/15

☐ 6/6 (port and starboard)

☐ 4/8 without 'Dog Watch'

☐ 4/8 with 'Dog Watch'

☐ 6/12

☐ Other (please specify)

Question 5: On this deployment, where did you stand watch (Check all that apply):

☐ Bridge

☐ Radio

☐ Engineering

☐ CIC

☐ Sonar

☐ Other (please specify)

Question 6: I found the 3/9 watch rotation to be <u>worse, the same as, or better</u> than the following watches:

☐ 5/10 (five and dime)

☐ 5/15

☐ 6/6 (port and starboard)

☐ 4/8 without 'Dog Watch'

☐ 4/8 with 'Dog Watch'

☐ 6/12

☐ Other (please specify)

(Check boxes for Worse than 3/9, Same as 3/9, Better than 3/9, and Never Stood this Watch)

Question 7: The amount of rest I received on the 3/9 watch rotation was (Check one):

☐ Much less than needed ☐ Less than needed

☐ About right ☐ More than needed

☐ Much more than needed

Question 8: The amount of rest received by other sailors on this cruise seemed (Check one):

☐ Much less than needed ☐ Less than needed

☐ About right ☐ More than needed

☐ Much more than needed

Question 9: I found the 3/9 watch rotation provided me with less, the same as, or more sleep than the following watches:

☐ 5/10 (five and dime) ☐ 5/15

☐ 6/6 (port and starboard) ☐ 4/8 without 'Dog Watch'

☐ 4/8 with 'Dog Watch' ☐ 6/12

☐ Other (please specify)

(Check boxes for Less sleep on 3/9, Same sleep on 3/9, More sleep on 3/9, and Never Stood this Watch)

2. Open-Ended Questions

There were three open-ended survey questions:

Question 10: What I liked most about the 3/9 watch is: ___________________________.

Question 11: What I liked least about the 3/9 watch is: ___________________________.

Question 12: Is there anything else you would like to tell us (good/bad) about the 3/9 four section watch rotation? ___________________________.

B. NOTIONAL WATCH SCHEDULES

A total of 29 various notional watch schedules for two, three, and four section duty were created to analyze in the FAST program. The watch schedule was input into FAST for a 30 day period of watches. The mean, minimum, and maximum of the predicted effectiveness while on watch was analyzed for each watch schedule to find which watch schedule results in the highest overall average predicted performance while on watch. Additionally the monthly variance of the predicted effectiveness, the percent of time below 70%, 80%, and 90% predicted effectiveness, and the average daily range between the minimum and maximum predicted effectiveness while on watch was analyzed.

The output from the FAST program is the predicted effectiveness for a person for each 30 minute period during the day. If a person was sleeping or not on watch, the FAST output for the predicted effectiveness was changed to 0 for the analysis in this thesis. This decision resulted in only the predicted effectiveness while on watch being analyzed. If there are two, three, or four people on watch during the day, the predicted effectiveness while on watch was averaged for all people standing watch during the day, and the analysis conducted using the data for all people standing watch.

1. Two Section Duty

With only two watch sections, there are not many permutations for types of two section watch. The following two section duty watches were analyzed for both people on watch during the day:

- Two section 6 hour watch (port / starboard)
- Two section 8-4-4-8 watch
- Two section 12 hour watch with no shifting of the watch

For the port/starboard watch, it is assumed that a person is awake for the half hour before and after standing watch, and that the person slept five hours per day between watches. The remaining 6 hours between watches was assumed to be spent awake. For the 8-4-4-8 watch and the 12 hour watch, it is assumed that a person is awake for the hour before and after standing watch, and that the person slept seven hours per day.

2. Three Section Duty

For all of the three section watches, it is assumed that an individual is awake for the hour before and after standing watch, and that the individual slept seven hours per day. The following three section duty watches were analyzed for all three people on watch during the day:

- Three section 4 hour watch with no shifting of the watch
- Three section 4 hour watch shifted forward each week on Sunday
- Three section 4 hour watch shifted forward each week on Sunday with no consecutive watches for any duty section
- Three section 4 hour watch shifted backwards each week on Sunday
- Three section 5 hour watch with no shifting of the watch
- Three section 5 hour watch shifted forward each week on Sunday
- Three section 5 hour watch shifted back each week on Sunday
- Three section 6 hour watch with no shifting of the watch
- Three section 6 hour watch shifted forward each week on Sunday
- Three section 6 hour watch shifted back each week on Sunday
- Straight eights (on watch for 8 hours and off 16 hours)
- Straight fours (on watch for 4 hours and off for 8 hours)

3. Four Section Duty

For all of the four section watches, it is assumed that an individual is awake for the hour before and after standing watch, and that the individual slept seven hours per day. The following four section duty watches were analyzed for all four people on watch during the day:

- Four section 3 hour watch with no shifting of the watch
- Four section 3 hour watch shifted forward each week on Sunday
- Four section 3 hour watch shifted forward each week on Sunday with no consecutive watches for any duty section
- Four section 3 hour watch shifted backwards each week on Sunday
- Four section 4 hour watch with no shifting of the watch
- Four section 4 hour watch shifted forward each week on Sunday
- Four section 4 hour watch shifted backwards each week on Sunday
- Four section 5 hour watch with no dogging or shifting of the watch
- Four section 5 hour watch shifted forward each week on Sunday
- Four section 5 hour watch shifted backwards each week on Sunday
- Four section 6 hour watch with no shifting of the watch
- Four section 6 hour watch shifted forward each week on Sunday
- Four section 6 hour watch shifted forward each week on Sunday with no consecutive watches for any duty section
- Four section 6 hour watch shifted backwards each week on Sunday

IV. ANALYSIS OF RESULTS

This chapter presents and summarizes the results of the analysis of the methods discussed in Chapter III. Section A presents the analysis of the survey data from the San Jacinto survey for the alternative 3/9 watch schedule for both the closed and open ended questions. Section B presents the results of the analysis of the predicted effectiveness while on watch for the notional watch schedules for two, three, and four section duty.

A. STATISTICAL ANALYSIS OF SURVEY DATA

1. Closed-Ended Questions

There were 112 survey respondents; five sailors answered No to Question 2: "Have you stood watch prior to this deployment?" and three sailors answered No to Question 3: "Did you work the current 3/9 hour watch rotation?" These eight records were removed from the data set. After the data were scrubbed and of the resulting 104 survey respondents, 92 were enlisted (88%) and 12 were officer (12%). Figure 13 shows the results of Question 1: "Please indicate your rank or rate."

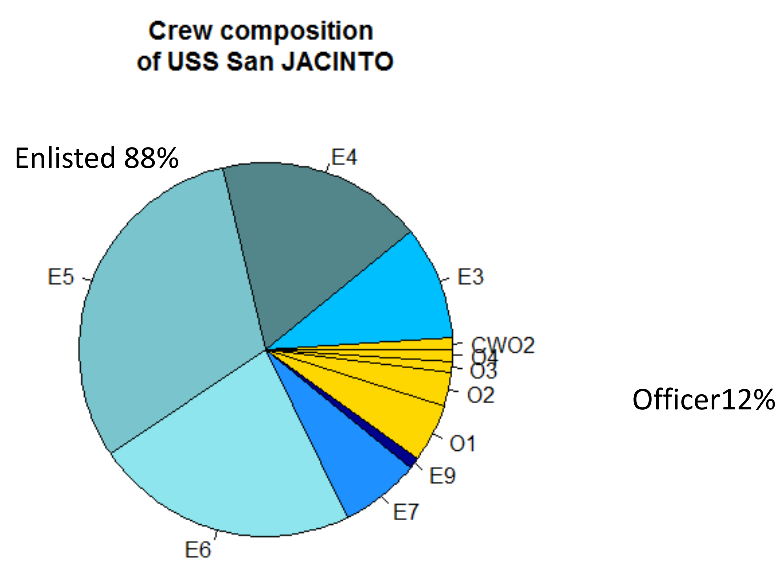


Figure 13. Crew ranks of USS San Jacinto survey respondents

Table 7 shows the percent of sailors who have previously stood various watch types for both enlisted and officers on the USS San Jacinto for Question 4: "Types of other watches I have stood." Fifty percent of both enlisted personnel and officers have stood either the 5/10, 6/6, or 6/12 watches.

Watch type previously stood	**Enlisted**	**Officer**
5/10 (five and dime)	85 %	83 %
5/15	60 %	33 %
6/6 (port and starboard)	87 %	50 %
4/8 without 'Dog watch'	39 %	25 %
4/8 with 'Dog watch'	45 %	50 %
6/12	67 %	50 %
Other	27 %	25 %

Table 7. Types of watch previously stood by percent of enlisted and officers on USS San Jacinto

Table 8 shows the results for the location of where respondents stood watch on the USS San Jacinto. Typically junior enlisted stood watch in just one location, while officers and senior enlisted stood watch in multiple locations. Question 5: "On this deployment, where did you stand watch."

Watch Area	**Number of enlisted standing watch**	**Number of officers standing watch**
Bridge	9	10
Engineering	34	3
Combat Information Center	40	8
Sonar	11	0
Other	9	8

Table 8. Watch location of survey respondents on USS San Jacinto

Figure 14 shows the results for enlisted respondents on the USS San Jacinto for Question 6: "I found the 3/9 watch rotation to be worse, the same, or better than the following watches." Enlisted personnel generally preferred the 3/9 watch and found that each other watch type was worse than the 3/9 except for the 5/15 watch.

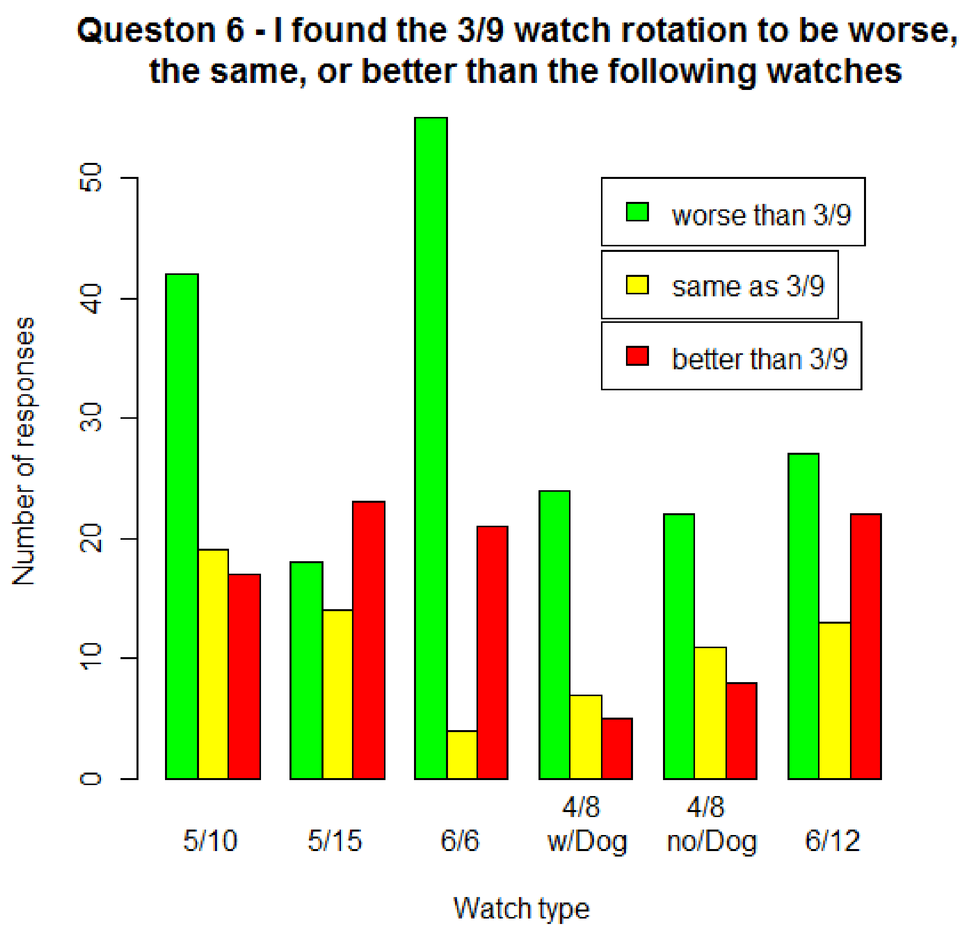


Figure 14. Preference of 3/9 watch compared to other watches for enlisted personnel

Figure 15 shows the results for officers on the USS San Jacinto for Question 6: "I found the 3/9 watch rotation to be worse, the same, or better than the following watches." Officers preferred the 3/9 watch over all other types of watch.

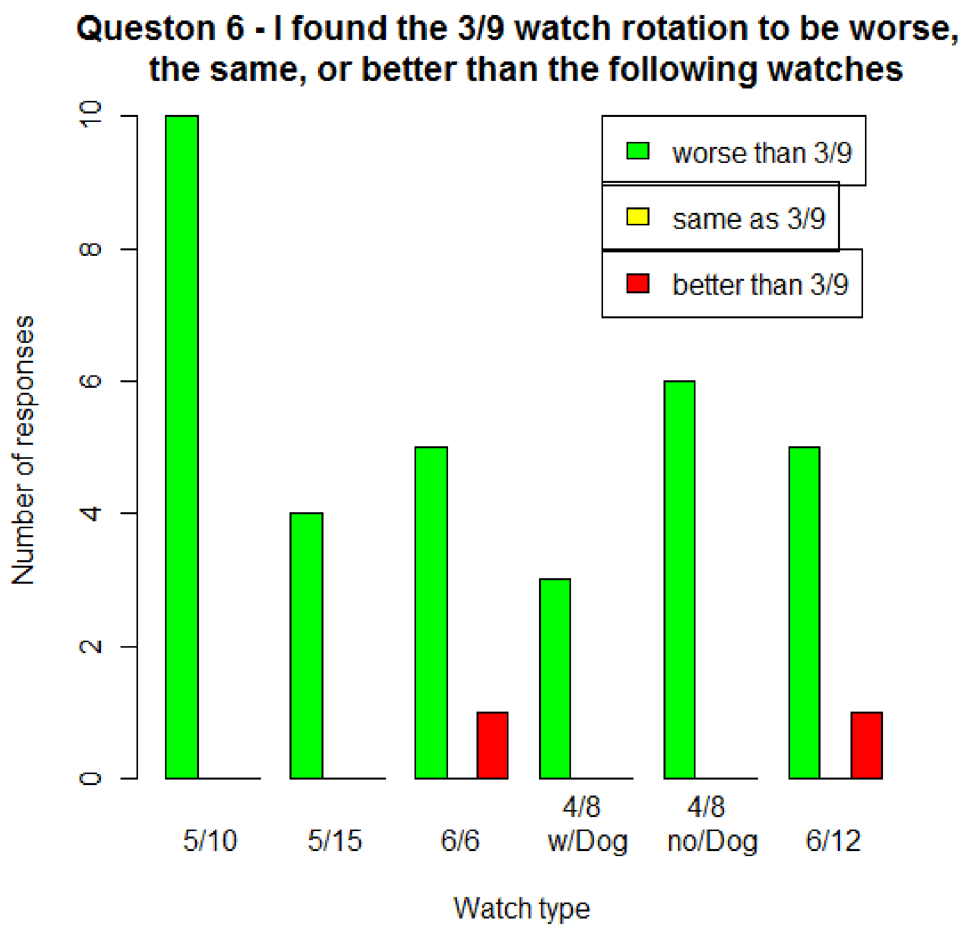


Figure 15. Preference of 3/9 watch compared to other watches for officers

Figure 16 shows the results for enlisted personnel on the USS San Jacinto for Question 7: "The amount of rest I received on the 3/9 watch rotation." Fifty-seven of the enlisted personnel (62%) said they received about the right amount of rest or more on the 3/9 watch rotation, while 35 of the enlisted personnel (38%) said they received less or much less rest on the 3/9 watch rotation.

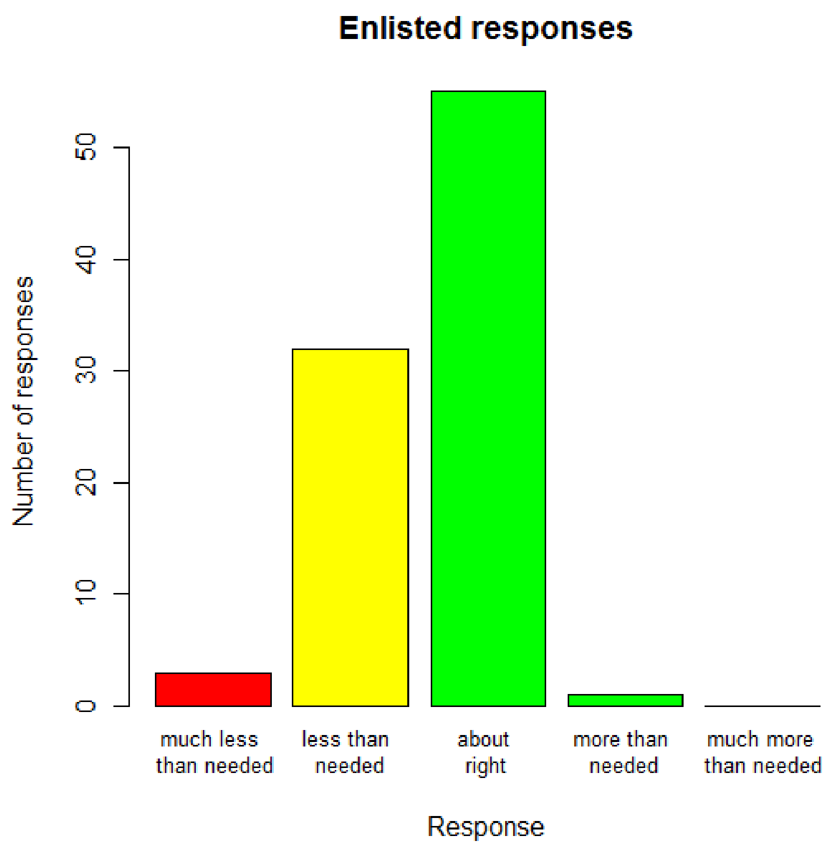


Figure 16. Amount of rest received by enlisted personnel on the 3/9 watch rotation

Figure 17 shows the results for officers on the USS San Jacinto for Question 7: "The amount of rest I received on the 3/9 watch rotation." All of the officers except for one said they received about the right amount of rest on the 3/9 watch rotation.

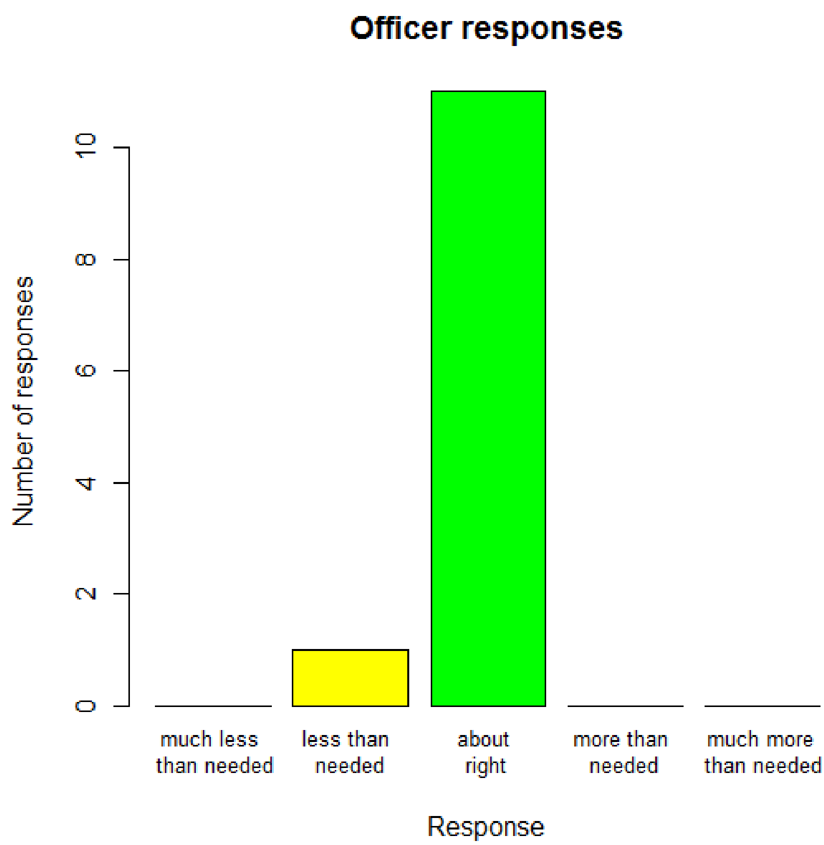


Figure 17. Amount of rest received by officers on the 3/9 watch rotation

Figure 18 shows the results for enlisted personnel on the USS San Jacinto for Question 8: "The amount of rest received by other sailors on the 3/9 watch rotation." Fifty-four of the enlisted personnel (59%) said they thought other sailors received about the right amount of rest or more than needed the 3/9 watch rotation. There were 38 enlisted personnel (41%) who said they received less rest than needed or much less rest than needed.

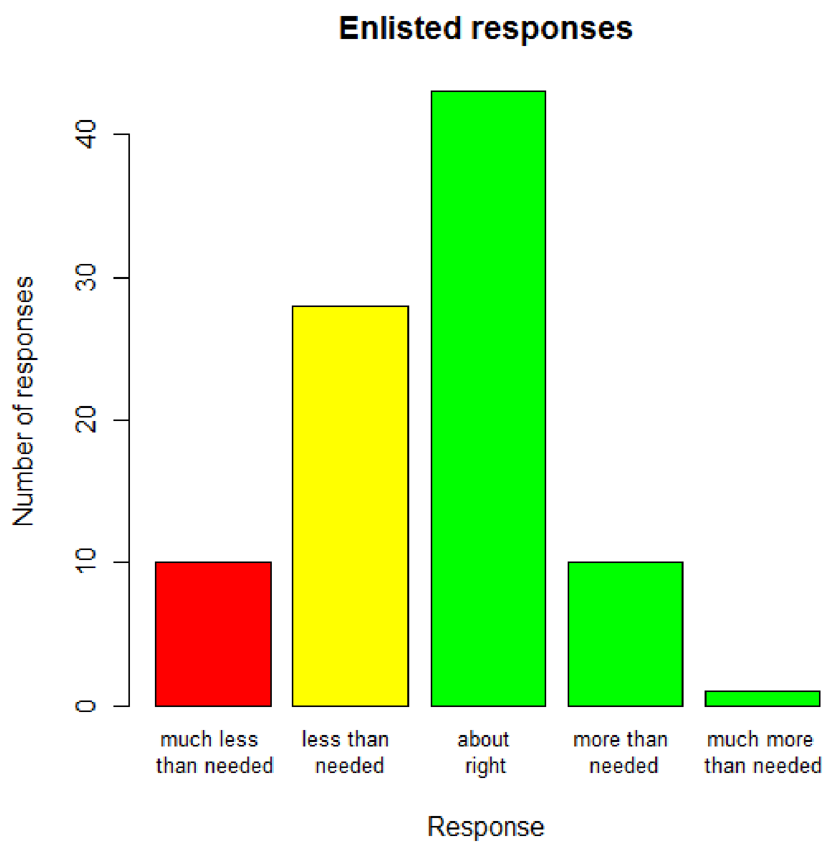


Figure 18. Enlisted responses for amount of rest received by other sailors on the 3/9 watch rotation

Figure 19 shows the results for officers on the USS San Jacinto for Question 8: "The amount of rest received by other sailors on the 3/9 watch rotation." Eight of the officers (67%) said they thought other sailors received about the right amount of rest or more than needed the 3/9 watch rotation. There were four (33%) who said they thought other sailors received less rest than needed or much less rest than needed.

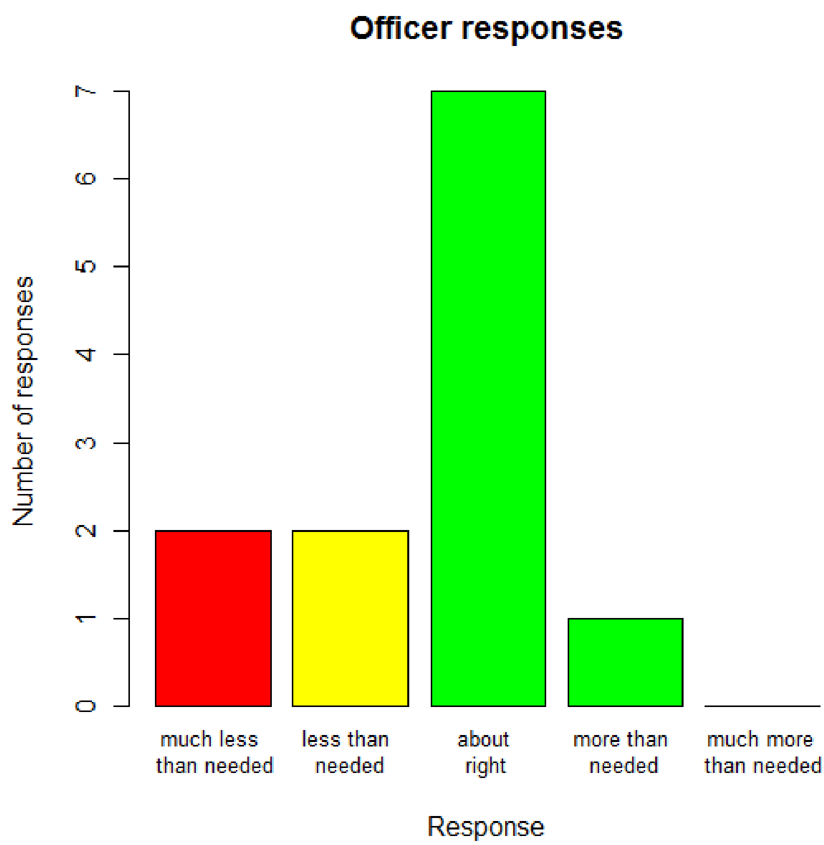


Figure 19. Officer responses for amount of rest received other sailors on the 3/9 watch rotation

Figure 20 shows the results for enlisted personnel on the USS San Jacinto for Question 9: "I found the 3/9 watch rotation provided me with less, the same as, or more sleep than the following watches." Most of the enlisted personnel said they received more sleep on the 3/9 watch rotation when compared to other watch rotations, except for the 5/15 watch. An large proportion of enlisted respondents said they received more sleep on the 3/9 watch rotation when compared to the 6/6 rotation.

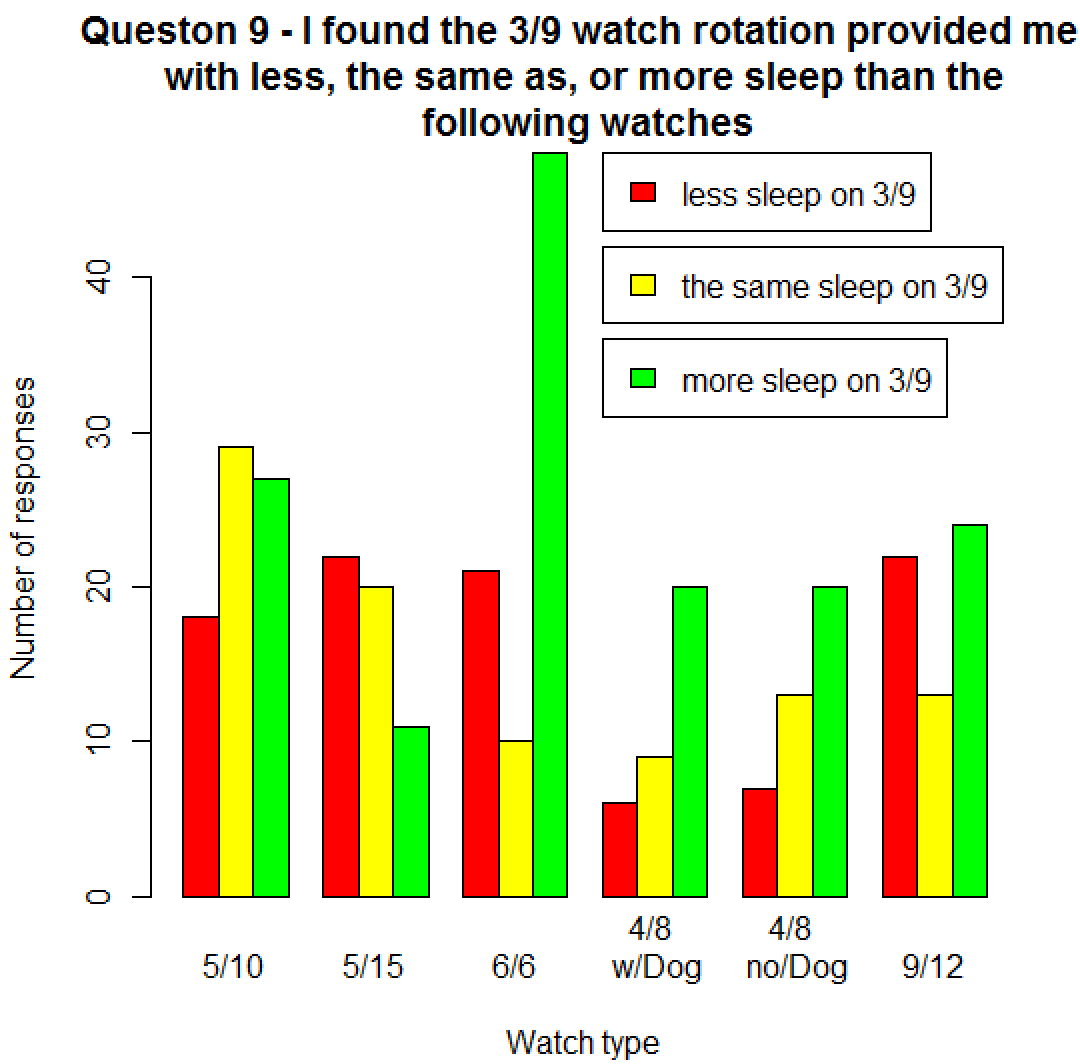


Figure 20. Enlisted responses for amount of sleep received on the 3/9 watch rotation

Figure 21 shows the results for officers on the USS San Jacinto for Question 9: "I found the 3/9 watch rotation provided me with less, the same as, or more sleep than the following watches." Most of the officers said they received more sleep on the 3/9 watch rotation when compared to other watch rotations, except for the 5/10 and 5/15 watches. There were two officers who said they received less sleep on the 3/9 watch when compared to the 5/10 watch, and two officers said they received less and more sleep on the 3/9 when compared to the 5/15 watch.

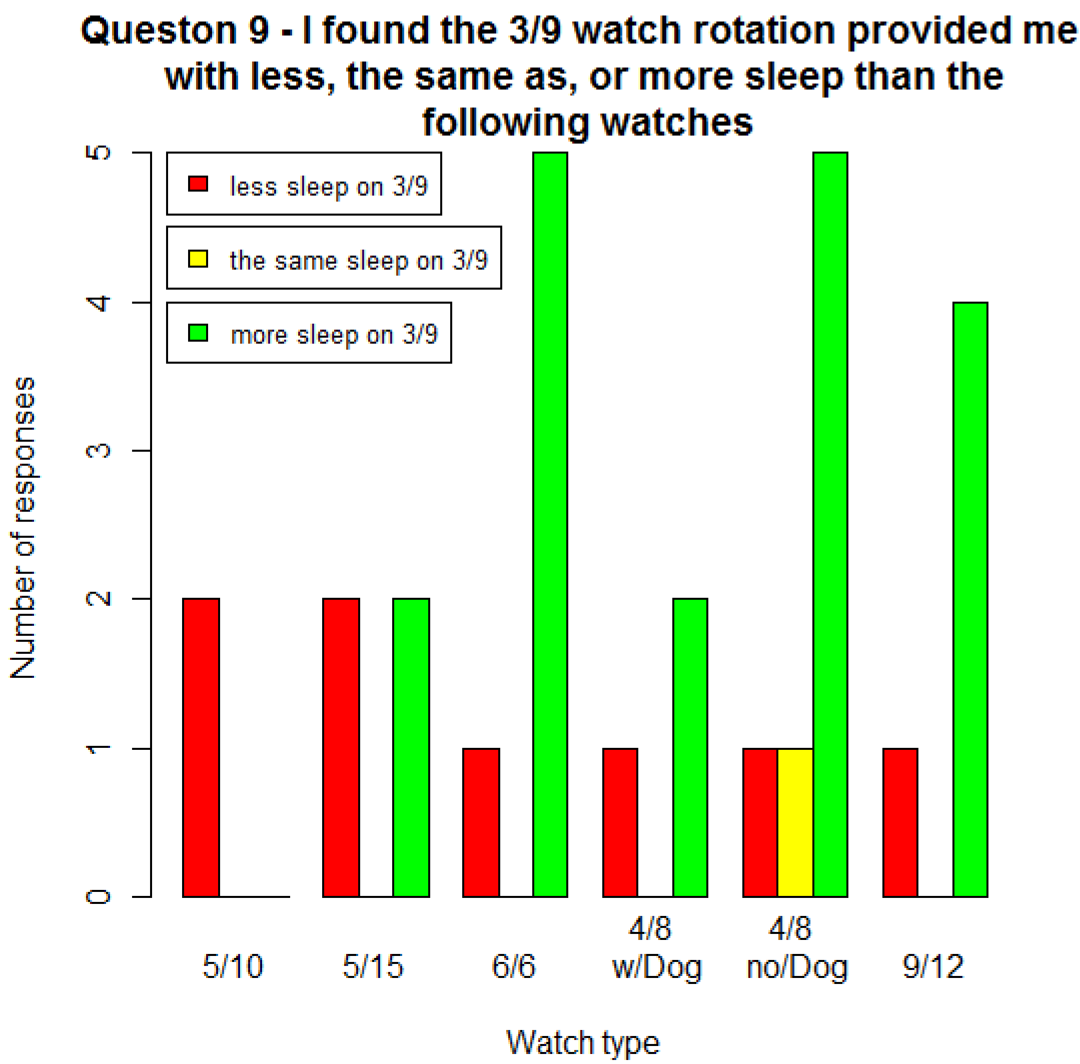


Figure 21. Officer responses for amount of sleep received on the 3/9 watch rotation

2. Open-Ended Questions

There were three questions in the USS San Jacinto survey where the crew could write what they wanted in response to the open ended questions. For analysis, the responses to the questions were categorized into different general responses. Some of the respondent's single open ended answers fell into multiple categories of response.

Figure 22 shows the results to Question 10: "What I liked most about the 3/9 watch is ________." Seventy-five percent of the officers liked that the 3/9 watch rotation was a set schedule or consistent, while 50% said they had more time to rest and 41.7% felt that they were more alert. Forty-five point seven percent of the enlisted crewmembers liked that the 3/9 watch rotation was a short watch, while 33.3% liked that it was a set schedule or consistent. None of the officers and 4.3% of the enlisted said they disliked the 3/9 watch.

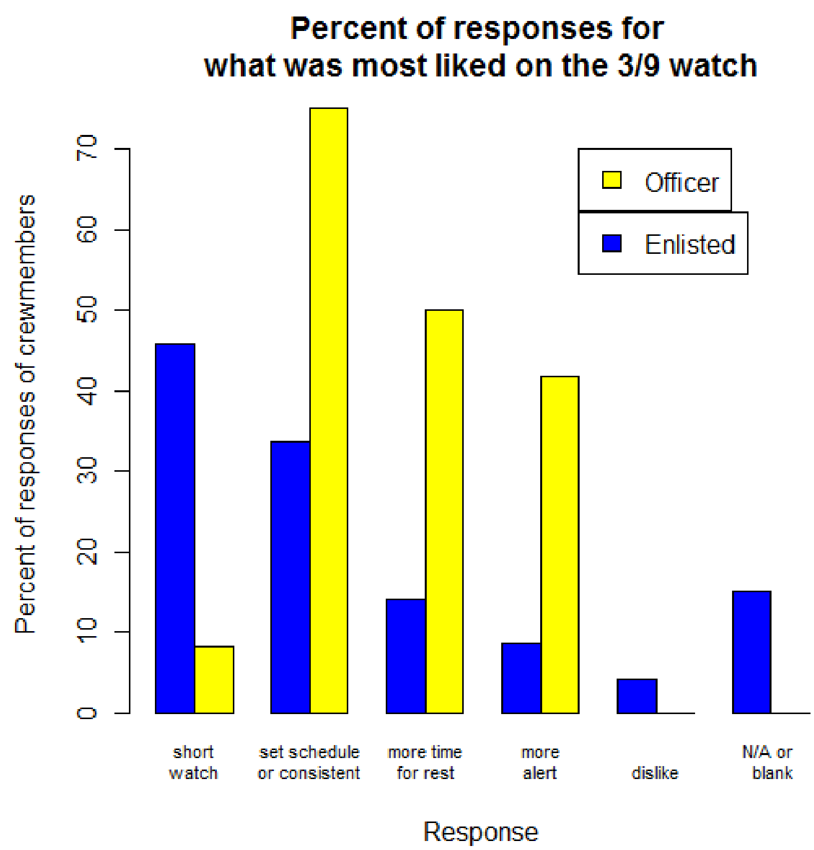


Figure 22. Percent of crew responses for what was most liked on the 3/9 watch rotation

A sample of some of the responses for Question 10 are given below:

> "I was focused better throughout the entire watch."
>
> "Able to stand a more attentive watch due to the shorter time period of 3 hours."
>
> "I can plan my weekday better. Sleep, PT time , is consistent. Can pay attention and stay alert when the watch is only 3 hours."
>
> "I could plan my day, develop a circadian rhythm, schedule regular gym time (which helped me lose 25 lbs) and get plenty of sleep. I was well rested and alert during all evolutions."

Figure 23 shows the results to Question 11: "What I liked least about the 3/9 watch is ________." Thirty-three point three percent of the officers did not like the odd hours on the 3/9 watch rotation, while 16.7% did not like that there were two watches in one day. Twenty-five percent of the enlisted did not like the odd hours, or thought that there was not enough time off on the 3/9 watch. Sixteen point seven percent of the officers and 14.1% of the enlisted said that there was nothing that they disliked about the 3/9 watch.

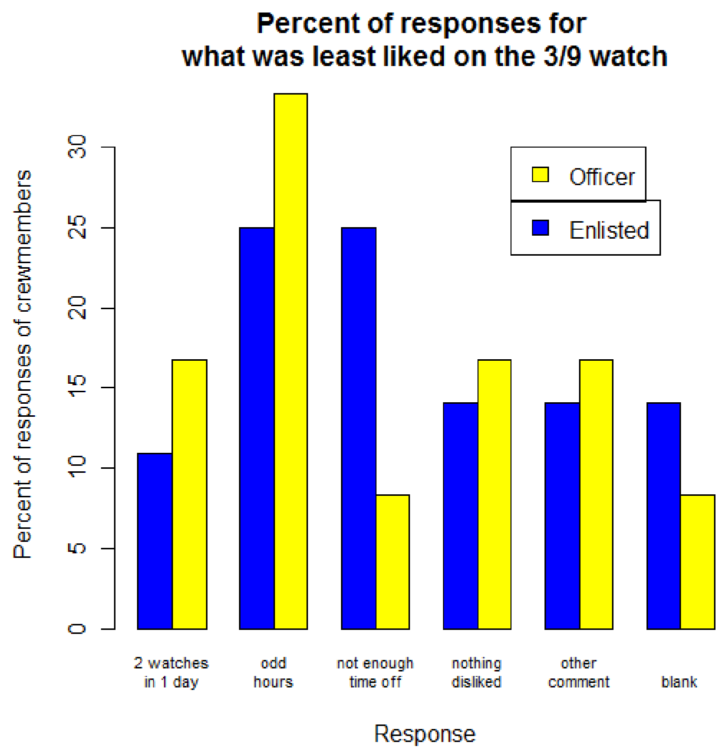


Figure 23. Percent of crew responses for what was least liked on the 3/9 watch rotation

A sample of some of the responses for Question 11 are given below:

> "I hate that I have to stand 2 watches a day."
>
> "Having the same watch every day."
>
> "12-3 and 3-6 mean you're still expected to do things during the day and there's virtually no sleep."
>
> "At times it wasn't supported with the plan of the day. All the meetings and important stuff for the day should be scheduled starting at 1000 and end about 1700 to support the late watches."

Figure 24 shows the results to Question 12: "Anything else to tell about the 3/9 watch." The answers to this question fell into four general categories: positive, neutral, negative comments, and N/A or none. Fifty-eight percent of the officers had positive comments about the 3/9 watch rotation, while no officers had any negative comments.

Twelve percent of the enlisted had positive comments about the 3/9 watch rotation and 13% had negative comments. Twenty-five percent of the officers and 63% of the enlisted said N/A or left the answer blank.

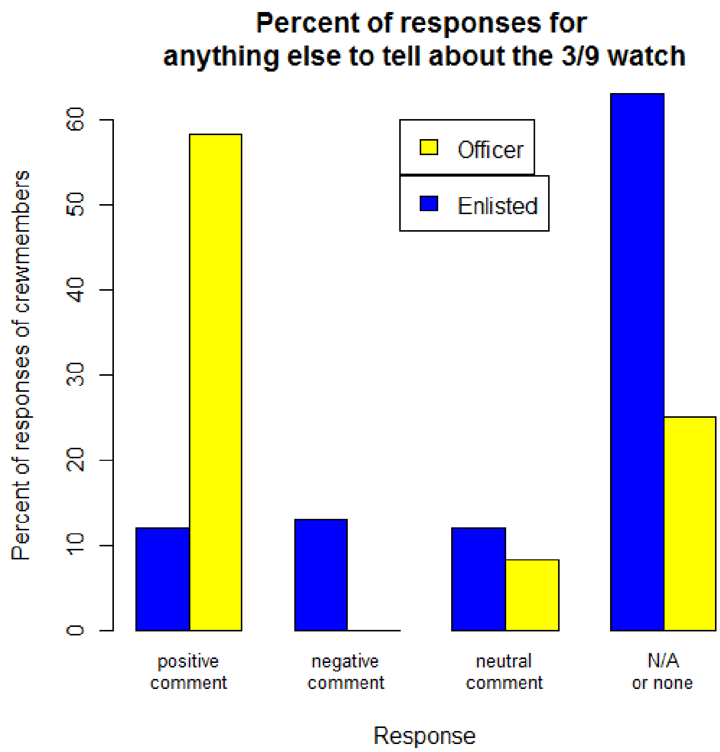


Figure 24. Percent of crew responses for what anything else to tell about the 3/9 watch rotation

Some of the responses for Question 12 were very positive, such as:

"Absolutely every ship in the Navy should switch to this model now. It is a night and day difference from how my entire first deployment went and I was in 5 section most of that time."

"Implement in the fleet!"

"All watchstanders seemed more alert and more rested with the 3\9 watch. Even if you have the night watch (00\03, 03\06), you can still get at least 6 hours of sleep a night . Any more than 3 straight hours of watch and withstanders fatigue."

"This should be the Navy standard."

while some sailors had negative comments, such as:

> "Get rid of it. I would rather stand 6 straight hours and be done for the day."

> "I can't plan my work outs with this rotation. Flight qtrs/work demand a lot of my time during this deployment."

> "The 6-9 watch was a killer. You get up at 0530 and work all day with no real downtime. But, you do get a full night of sleep. The 3-6 is also rough at 1800 when you get off you usually have things that need to be wrapped up so getting done by 2000 to get 6 hours sleep was a challenge. I'm on the 3-6 now and it is 2100. I have about 1.5 before I go to sleep"

Overall, the crew of the USS San Jacinto liked the 3/9 watch schedule and thought they received more rest on the 3/9 schedule when compared to other watches. The survey results will be further discussed in the conclusion of this thesis in Section V.

B. NOTIONAL USE CASES OF WATCH SCHEDULES

1. Two Section Duty

Three two section duty notional watch schedules were analyzed in the FAST program. The 6/6, 12/12, and 8-4-4-8 watches were all analyzed with no shifting of the watch. Table 9 shows a comparison of the predicted effectiveness output from the FAST program for all of the notional watch schedules for two section duty. The minimum, mean, maximum, mean daily range, and monthly variance of the predicted effectiveness while on watch averaged over a 30 day period are given.

Two section duty	Min	Predicted Effectiveness Mean	Max	Mean Daily Range	Monthly Variance
6-6 (port / starboard watch)	65.56	79.19	91.34	13.84	24.3
8-4-4-8 watch no shifting	56.89	85.92	92.04	13.83	49.28
12-12 watch	68.09	90.61	97.05	6.5	51.79

Table 9. Comparison of predicted effectiveness for two section duty notional watch schedules

Table 10 shows the percent of time below 90%, 80%, and 70% predicted effectiveness for the two section duty notional watch schedules. Since 70% predicted effectiveness corresponds to a 0.08 BAC level, the percent of time spent below 70% predicted effectiveness is of concern because below this level the person's reaction time are similar as to reaction times when they are legally intoxicated.

Two section duty	Percent of time < 90% predicted effectiveness	Percent of time < 80% predicted effectiveness	Percent of time < 70% predicted effectiveness
6-6 (port / starboard watch)	99.4	40.7	8
8-4-4-8 watch no shifting	74.5	10.8	6.3
12-12 watch	23.3	12.7	1.5

Table 10. Percent of time below various levels of predicted effectiveness for two section duty notional watch schedules

Results showed that the 12/12 watch was the best of the two section watches with the highest mean, minimum, and maximum predicted effectiveness, lowest mean daily range, and lowest percent of time below 70% predicted effectiveness (1.5%). The watchstanders on this watch stand the same watch and sleep the same hours each day, so their circadian rhythms are not adversely affected. Additionally watchstanders on this watch can get seven hours of sleep (or more), whereas they can likely only get five hours of sleep if standing a 6/6 watch. This watch resulted in the highest predicted effectiveness while on watch.

Figure 25 shows a screenshot of the FAST output in graphical form for an individual standing the 12/12 watch. The predicted effectiveness is denoted by the black cyclic line at the top of the graph, while the predicted effectiveness while on watch is the darker part of the line. The predicted effectiveness while on watch gradually improves as this individual became used to their sleep schedule. Most of the time the predicted effectiveness while on watch is over 90%.

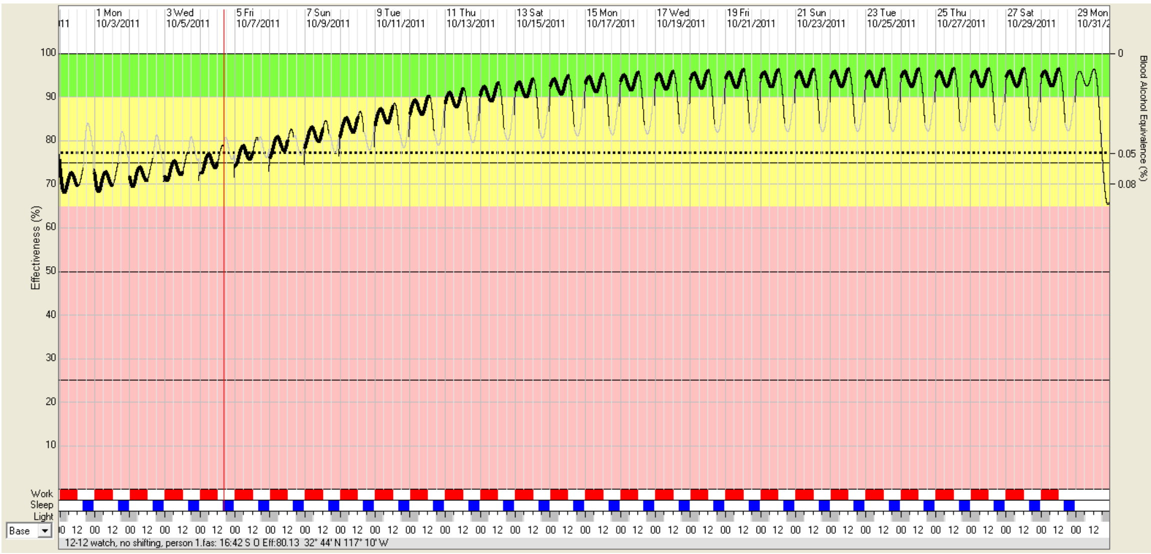


Figure 25. Predicted effectiveness for a watchstander on the 12/12 watch rotation

The data for both watchstanders on the 12/12 watch was combined to analyze the overall predicted effectiveness while on watch for all watchstanders. Figure 26 shows a histogram of the predicted effectiveness of watchstanders on the 12/12 watch. Overall, both individuals standing this watch have a mean 90.6% predicted effectiveness while on watch, with only 1.5% of the time an individual's predicted effectiveness while on watch falls below 70%. It should be noted that there is no shifting – that is sailors always stand the same watch on any of the two section watches evaluated.

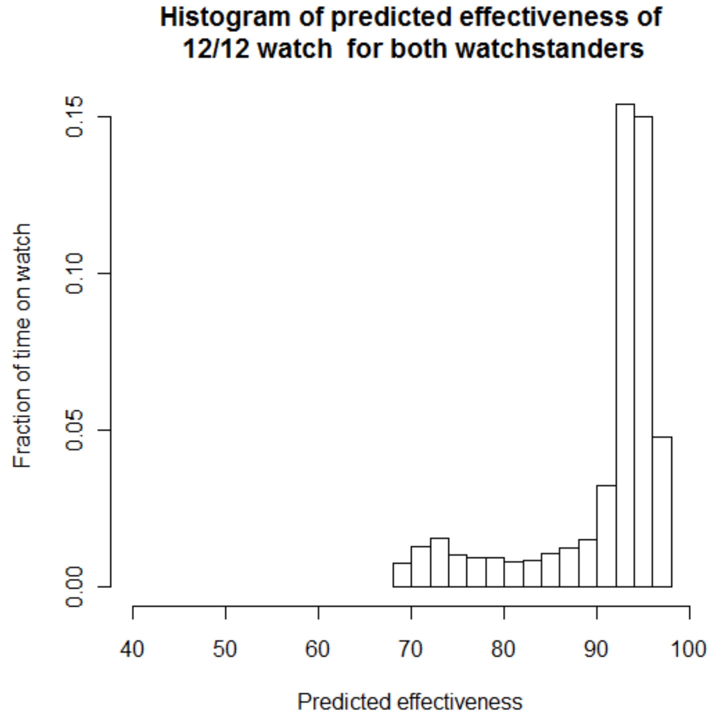


Figure 26. Histogram of predicted effectiveness for both watchstanders on the 12/12 watch rotation

In contrast to the high predicted effectiveness of the watchstanders while on watch for the 12/12 schedule, the 6/6 schedule results in very low predicted effectiveness levels while on watch. Figure 27 shows the predicted effectiveness for an individual standing the 6/6 watch rotation. The predicted effectiveness while on watch is volatile (with the average daily range of 13.8% predicted effectiveness), and all of the time on watch is spent in the yellow range on the graph.

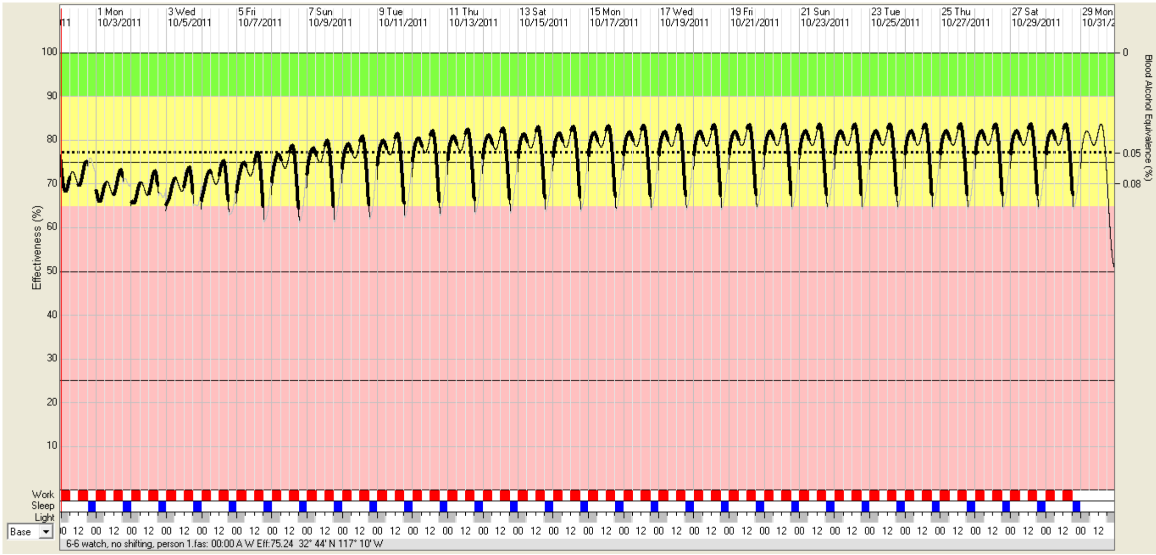


Figure 27. Predicted effectiveness for an individual on the 6/6 watch rotation

The data for watchstanders on the 6/6 watch was combined to analyze the overall predicted effectiveness while on watch for both watchstanders. Figure 28 shows a histogram of the predicted effectiveness of both watchstanders on the 6/6 watch. Overall, both individuals standing this watch have a mean 79.2% predicted effectiveness while on watch; 8% of the time, a person's predicted effectiveness while on the 6/6 watch falls below 70%.

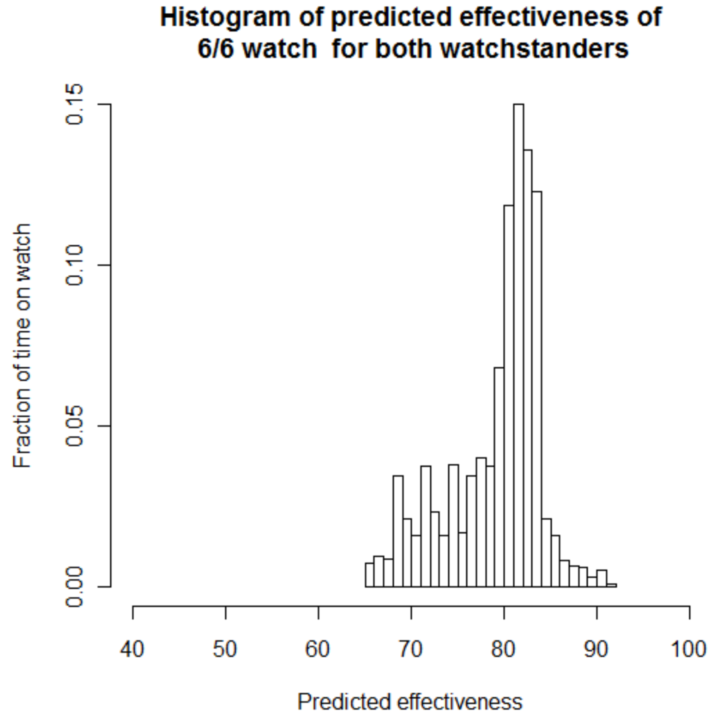


Figure 28. Histogram of predicted effectiveness for both watchstanders on the 6/6 watch rotation

2. Three Section Duty

There were a total of 12 three section duty notional watch schedules analyzed in the FAST program. The 4/8, 5/10, and 6/12 watches were all analyzed with a) no shifting of the watch, b) shifting of the watch forward weekly each Sunday, and c) shifting the watch back weekly each Sunday. If the watch is shifted forward, then one duty section is standing back to back watch from the Saturday night before the shift to the shift of the watch section occurring on Sunday. An alternative for this is for two of the other duty sections to stand a longer, six hour watch on the Saturday night watch to cover for the watch section that has the first shift on Sunday morning, which is done for the 4/8 watch. Additionally, a straight eights watch schedule (where an individual stands watch eight hours straight with 16 hours off) and straight fours (where an individual stands watch four hours straight with 8 hours off) watch section are analyzed, Table 11 shows the straight fours watch, which enables each member of the watch team to sleep during the evening or night, and be up during the day from 0730 to 1630.

Time	Work	Sleep	
0100	Team 1		Team 2
0200	Team 1	Team 3	Team 2
0300	Team 1	Team 3	Team 2
0400	Team 1	Team 3	
0500	Team 2	Team 3	
0600	Team 2	Team 3	
0700	Team 2	Team 3	
0800	Team 2		
0900	Team 3		
1000	Team 3		
1100	Team 3		
1200	Team 3		
1300	Team 1		
1400	Team 1		
1500	Team 1		
1600	Team 1		
1700	Team 2		
1800	Team 2	Team 1	
1900	Team 2	Team 1	
2000	Team 2	Team 1	
2100	Team 3	Team 1	
2200	Team 3	Team 1	Team 2
2300	Team 3	Team 1	Team 2
2400	Team 3		Team 2

Table 11. Straight fours watch section

Table 12 shows a comparison of the predicted effectiveness output from the FAST program for all of the notional watch schedules for three section duty, while Table 13 shows the percent of time below 90%, 80%, and 70% predicted effectiveness for the two section duty notional watch schedules.

Three section duty	Min	Predicted Effectiveness Mean	Max	Mean Daily Range	Monthly Variance
4-8 no shifting	66.81	86.75	92.92	8.68	30.16
5-10 no shifting	46.34	82.54	93.38	17.32	75.97
6-12 no shifting	45.39	81.22	95.75	11.06	100.1
4-8 shifted back weekly on Sunday	54.11	78.31	92.97	12.2	68.25
5-10 shifted back weekly on Sunday	53.22	81.69	93.46	16.59	71.83
6-12 shifted back weekly on Sunday	47.81	81.67	95.81	10.95	88.15
4-8 shifted forward weekly on Sunday	57.43	79.06	92.97	12.13	101.1
5-10 shifted forward weekly on Sunday	52.05	82.56	94.2	17.29	78.43
6-12 shifted forward weekly on Sunday	47.99	83.59	98.33	11.03	102.8
4-8 shifted forward weekly on Sunday no consecutive watches	60.55	79.79	97.97	11.58	89.5
straight fours	68.09	91.86	96.93	8.63	35.57
straight eights	64.5	88.29	100	5.11	157.1

Table 12. Comparison of predicted effectiveness for three section duty notional watch schedules

Three section duty	Percent of time < 90% predicted effectiveness	Percent of time < 80% predicted effectiveness	Percent of time < 70% predicted effectiveness
4-8 no shifting	68.7	10.5	2.8
5-10 no shifting	86.4	29.7	1.1
6-12 no shifting	79.8	37.1	14.6
4-8 shifted back weekly on Sunday	95.9	51.2	16.5
5-10 shifted back weekly on Sunday	87.2	35.5	10.2
6-12 shifted back weekly on Sunday	78.3	40.7	11.6
4-8 shifted forward weekly on Sunday	87.1	45.6	2.4
5-10 shifted forward weekly on Sunday	80.8	28.8	11.6
6-12 shifted forward weekly on Sunday	62.5	27.8	12.9
4-8 shifted forward weekly on Sunday no consecutive watches	86.7	42.5	22.2
straight fours	24.4	6.9	0.8
straight eights	37.3	31.3	15.4

Table 13. Percent of time below various levels of predicted effectiveness for three section duty notional watch schedules

The straight fours watch was the best type of watch with the highest mean and minimum predicted effectiveness, lowest variance, and lowest percent of time below 70% predicted effectiveness (0.8%). The watchstanders on this watches stand the same watch and sleep the same hours each day, so their circadian rhythms are not adversely affected. This resulted in the highest predicted effectiveness while on watch. Figure 29 shows a screenshot of the FAST output in graphical form for an individual standing the straight fours watch. Most of the time the predicted effectiveness while on watch is over 90%.

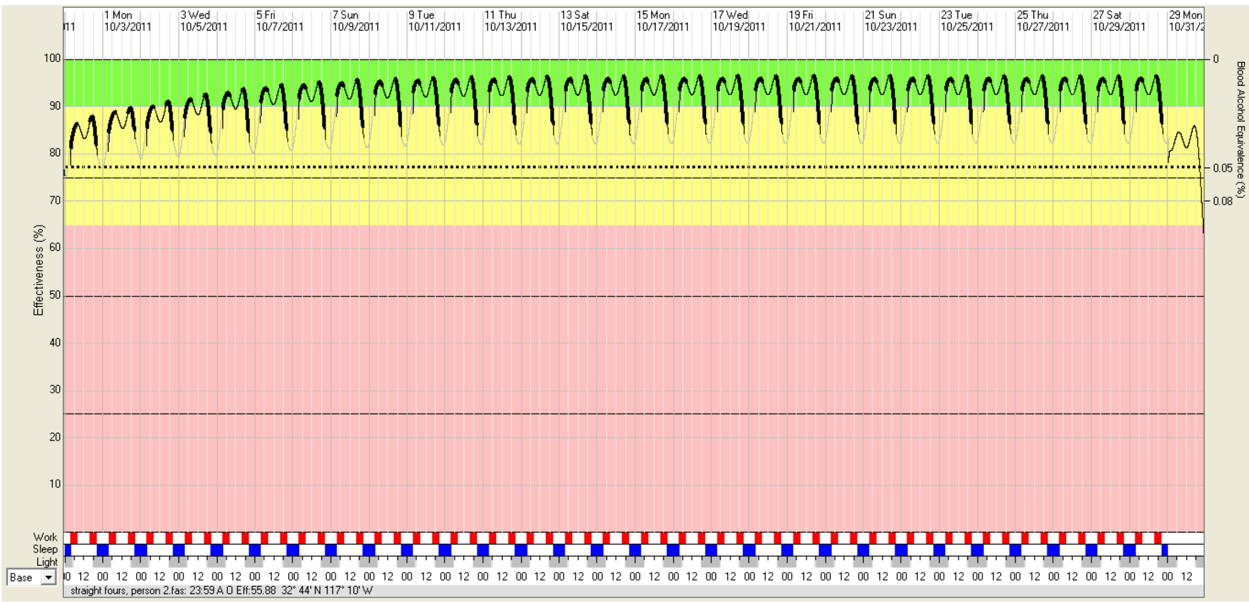


Figure 29. Predicted effectiveness for an individual on the straight fours watch rotation

The data for both people standing the straight fours watch was combined to analyze the overall predicted effectiveness while on watch for all watchstanders. Figure 30 shows a histogram of the predicted effectiveness of all people standing the straight fours watch. Overall, all four people standing this watch have a mean 91.86% predicted effectiveness while on watch.

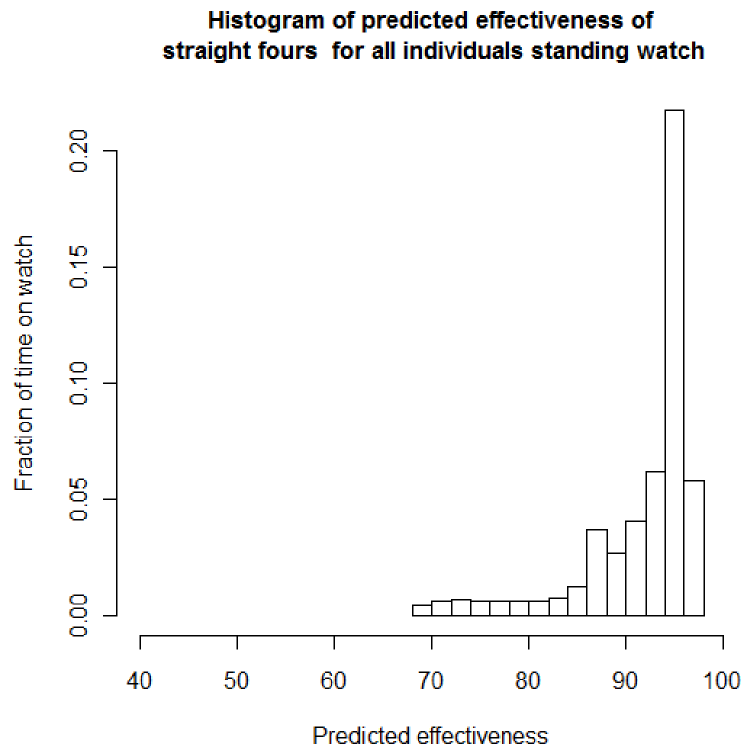


Figure 30. Histogram of predicted effectiveness for all watchstanders on the straight fours watch rotation

In contrast to the high predicted effectiveness of the watchstanders while on watch for the straight fours schedule, the 4/8 schedule shifted back each Sunday has much lower predicted effectiveness. Figure 31 shows the predicted effectiveness for an individual standing the 4/8 watch rotation shifted back weekly each Sunday. The predicted effectiveness while on watch is volatile, and the watchstanders spends much time in the yellow section and below 70%.

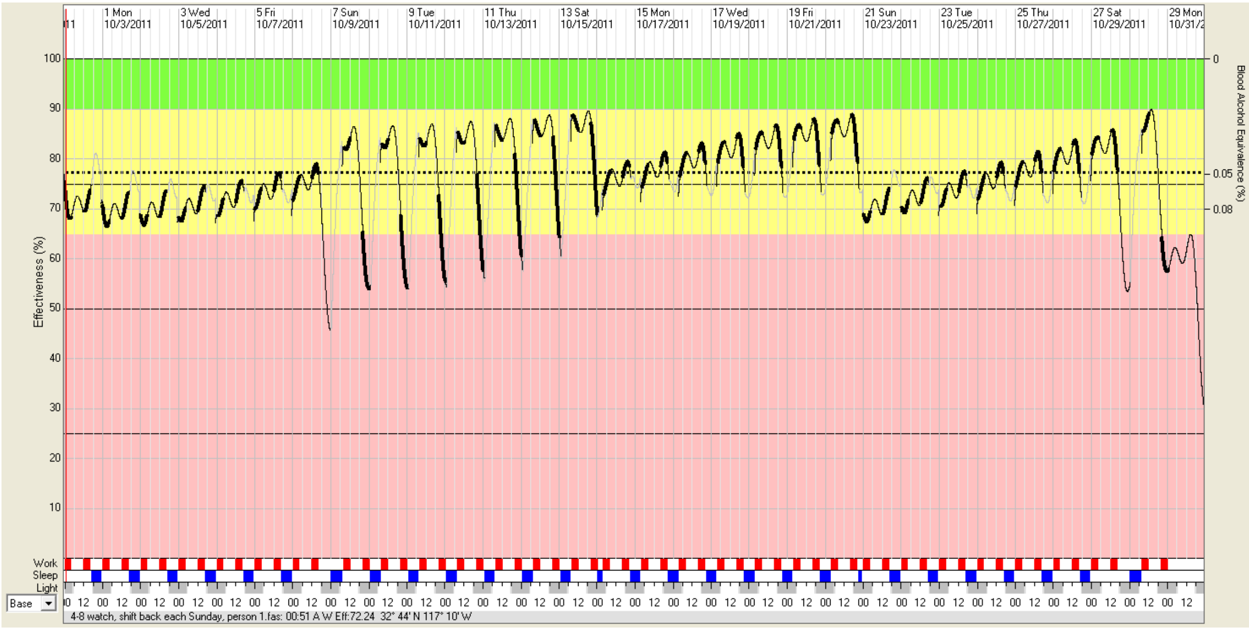


Figure 31. Predicted effectiveness for an individual on the 4/8 watch rotation shifted back each Sunday

The data for watchstanders on the 4/8 watch shifted backwards each Sunday was combined to analyze the overall predicted effectiveness while on watch for all watchstanders. Figure 32 shows a histogram of the predicted effectiveness of watchstanders on the 4/8 watch shifted backwards each Sunday. Overall, all three people standing this watch have a mean 78.31% predicted effectiveness while on watch, with 51.2% of the time, an individual's predicted effectiveness falls below 80%. In 16.5% of the time, an individual's predicted effectiveness falls below 70%. This schedule is worse than the straight fours schedule mentioned previously.

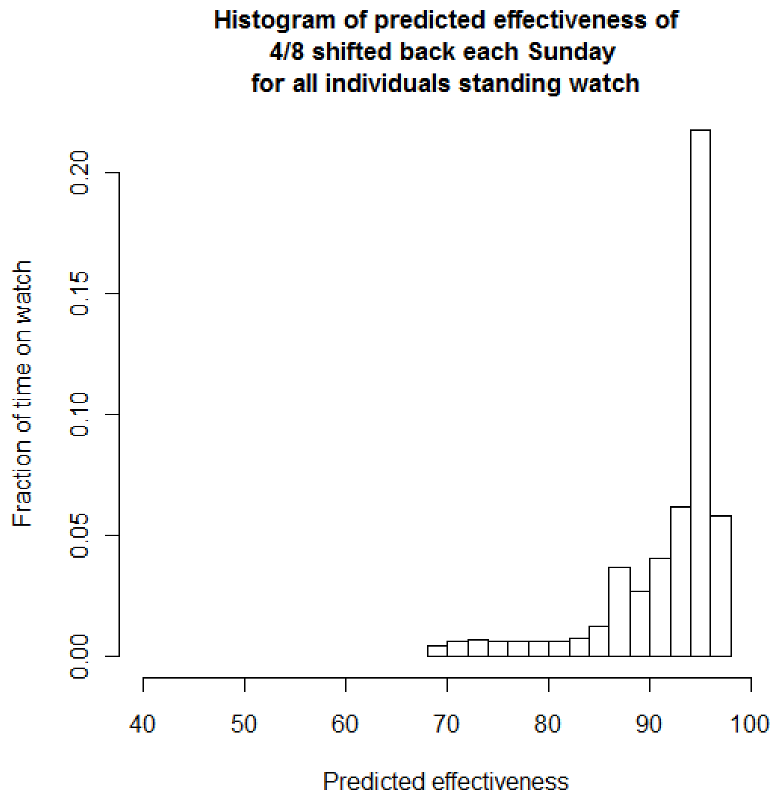


Figure 32. Histogram of predicted effectiveness for all watchstanders on the 4/8 watch rotation shifted back weekly each Sunday

The watch schedule with no shifting for three section duty is the 4/8 schedule shifted forward each Sunday so no individual stands consecutive watches. This is accomplished by two of the other duty sections standing a longer six hour watch on the Saturday watch to cover for the watch section that has the first shift on Sunday morning. Figure 33 shows the predicted effectiveness for an individual standing the 4/8 watch shifted forward each Sunday so no individual stands consecutive watches. Most of the time the predicted effectiveness while on watch is in the yellow section between 65 and 90%.

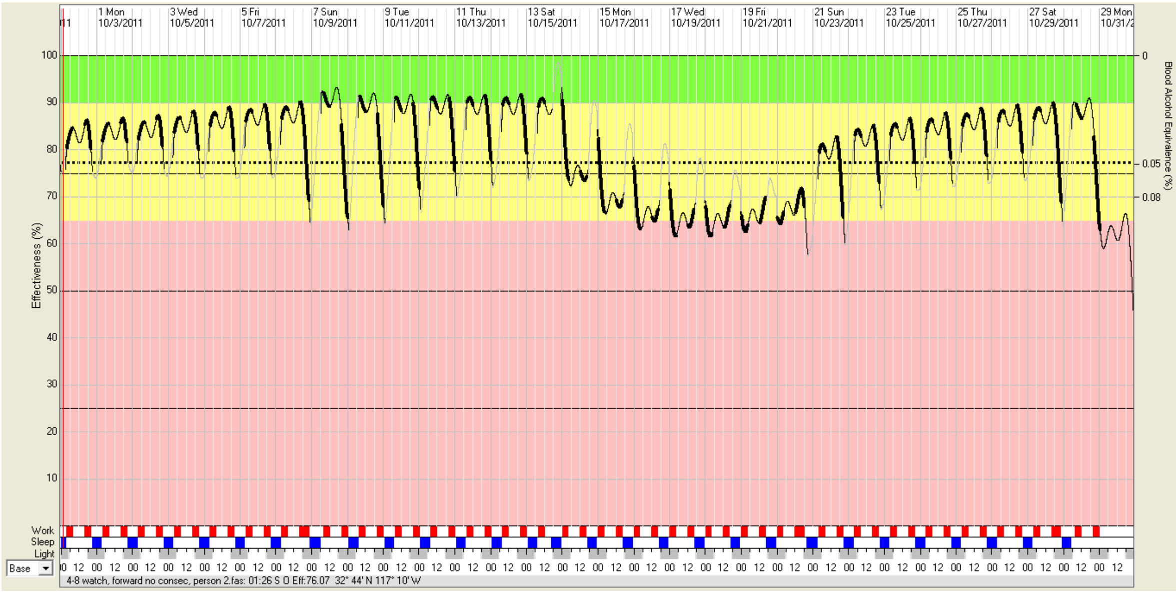


Figure 33. Predicted effectiveness for an individual on the 4/8 watch rotation shifted forward each Sunday with no consecutive watches

The data for watchstanders on the 4/8 watch shifted forward each Sunday with no consecutive watches was combined to analyze the overall predicted effectiveness while on watch for all watchstanders. Figure 34 shows a histogram of the predicted effectiveness of watchstanders on the 4/8 watch shifted forward each Sunday with no consecutive watches. Overall, all three people standing this watch have a mean 79.79% predicted effectiveness while on watch, with 42.5% of the time, an individual's predicted effectiveness falls below 80%. In 22.2% of the time, an individual's predicted effectiveness falls below 70%.

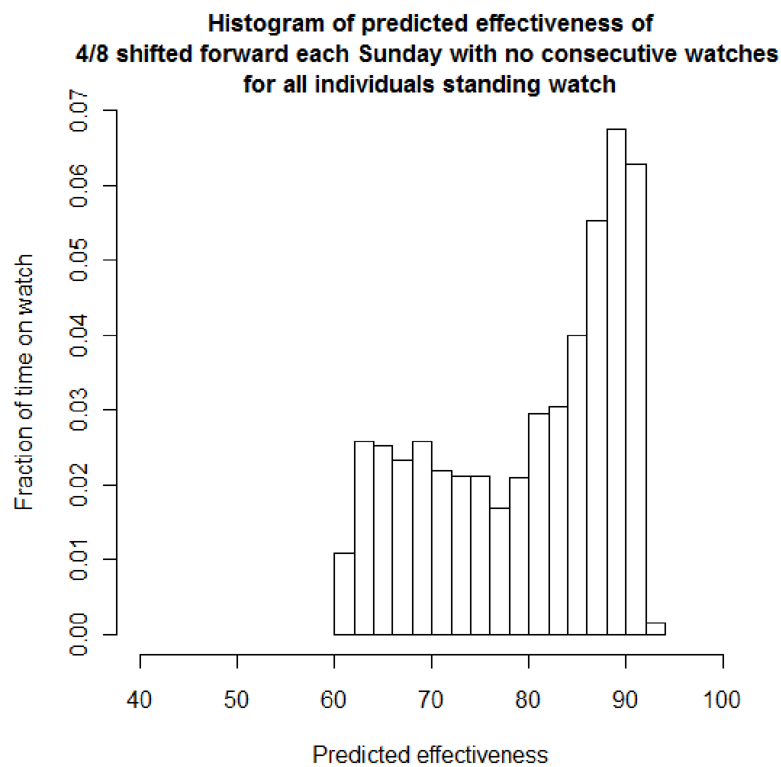


Figure 34. Histogram of predicted effectiveness for all watchstanders on the 4/8 watch rotation shifted forward weekly each Sunday with no consecutive watches

3. Four Section Duty

There were a total of 14 four section duty notional watch schedules analyzed in the FAST program. The 3/9, 4/12, 5/15, and 6/18 watches were all analyzed with no shifting of the watch, shifting of the watch forward weekly each Sunday, and shifting the watch back weekly each Sunday. If the watch is shifted forward, then one duty section is standing back to back watch from the Saturday night before the shift to the shift of the watch section occurring on Sunday. An alternative for this schedule is for three of the other duty sections to stand a longer watch on the Saturday watch to cover for the watch section that has the first shift on Sunday morning. This schedule is calculated for the 3/9 and 6/18 watches. Table 14 shows an example of the 3/9 watch shifted forward on Sunday with three of the duty sections standing a longer four hour watch on the Saturday before the shift.

Watch before shifting					
Time	**Work**	**Sleep**			
0100	1		2	3	
0200	1		2	3	4
0300	1			3	4
0400	2			3	4
0500	2			3	4
0600	2				4
0700	3				4
0800	3				4
0900	3				
1000	4				
1100	4				
1200	4				
1300	1				
1400	1				
1500	1				
1600	2				
1700	2	1			
1800	2	1			
1900	3	1			
2000	3	1	2		
2100	3	1	2		
2200	4	1	2		
2300	4	1	2	3	
2400	4		2	3	

Saturday before shifting					
Time	**Work**	**Sleep**			
0100	1		2	3	
0200	1		2	3	4
0300	1			3	4
0400	2			3	4
0500	2			3	4
0600	2				4
0700	3				4
0800	3				4
0900	3				
1000	4				
1100	4				
1200	4				
1300	1				
1400	1				
1500	1				
1600	1				
1700	2				
1800	2				
1900	2				
2000	2	1			
2100	3	1			
2200	3	1			
2300	3	1	2		
2400	3	1	2		

Sunday shifting of watch					
Time	**Work**	**Sleep**			
0100	4	1	2		
0200	4	1	2	3	
0300	4		2	3	
0400	1		2	3	
0500	1		2	3	
0600	1			3	
0700	2			3	
0800	2			3	
0900	2				
1000	3				
1100	3				
1200	3				
1300	4				
1400	4				
1500	4				
1600	1				
1700	1				4
1800	1				4
1900	2				4
2000	2	1			4
2100	2	1			4
2200	3	1			4
2300	3	1	2		4
2400	3	1	2		

Table 14. 3/9 watch shifted forward on Sunday with no consecutive watches

Table 15 shows a comparison of the predicted effectiveness output from the FAST program for all of the notional watch schedules for four section duty, while Table 16 shows the percent of time below 90%, 80%, and 70% predicted effectiveness for the four section duty notional watch schedules.

Four section duty	Min	Predicted Effectiveness Mean	Max	Mean Daily Range	Monthly Variance
3-9 no shifting	68.24	92.56	97.61	5.92	32.13
4-12 no shifting	60.12	85.12	94.53	6.86	33.28
5-15 no shifting	43.95	89.56	95.56	13.15	135.9
6-18 no shifting	68.09	93.6	99.71	4.16	36.3
3-9 shifted back weekly on Sunday	59.46	87.5	100	10.36	73.13
4-12 shifted back weekly on Sunday	47.74	82.68	99.24	7.66	77.03
5-15 shifted back weekly on Sunday	43.98	83.8	95.79	13.44	130.28
6-18 shifted back weekly on Sunday	47.41	84.98	99.73	10.92	127.68
3-9 shifted forward weekly on Sunday	35.01	87.45	97.61	12.5	102.15
4-12 shifted forward weekly on Sunday	58.56	85.26	97.21	7.56	42.71
5-15 shifted forward weekly on Sunday	43.95	83.4	95.79	12.23	139.41
6-18 shifted forward weekly on Sunday	60.88	86.77	98	8.33	112.5
3-9 shifted forward weekly on Sunday no consecutive watches	64.23	88.34	100	9.69	81.32
6-18 shifted forward weekly on Sunday no consecutive watches	34.27	87.12	98	7.32	102.96

Table 15. Comparison of predicted effectiveness for four section duty notional watch schedules

Four section duty	Percent of time < 90% predicted effectiveness	Percent of time < 80% predicted effectiveness	Percent of time < 70% predicted effectiveness
3-9 no shifting	15.7	5.8	1.1
4-12 no shifting	76.3	24.6	0.7
5-15 no shifting	51.4	24.7	16.3
6-18 no shifting	10.3	5.8	1.3
3-9 shifted back weekly on Sunday	49.5	15.4	7.7
4-12 shifted back weekly on Sunday	78.6	33.3	8
5-15 shifted back weekly on Sunday	53.2	25.8	15.6
6-18 shifted back weekly on Sunday	48	34.7	11
3-9 shifted forward weekly on Sunday	44.2	22.6	8.1
4-12 shifted forward weekly on Sunday	70.6	23.3	1.8
5-15 shifted forward weekly on Sunday	54.6	28.4	17
6-18 shifted forward weekly on Sunday	41	25.3	1.2
3-9 shifted forward weekly on Sunday no consecutive watches	43	19.7	6.4
6-18 shifted forward weekly on Sunday no consecutive watches	39.7	24.4	11.6

Table 16. Percent of time below various levels of predicted effectiveness for four section duty notional watch schedules

The 3/9 and 6/18 watches with no shifting resulted in the highest mean and minimum predicted effectiveness, lowest variance, and lowest percent of time below 70% predicted effectiveness (1.1% and 1.3%, respectively). The watchstanders on these watches stand the same watch and sleep the same hours each day, so their circadian rhythms are not adversely affected. This resulted in the highest predicted effectiveness while on watch. Figure 35 shows a screenshot of the FAST output in graphical form for an individual standing the 3/9 watch with no shifting. Most of the time the predicted effectiveness while on watch is over 90%, and the mean daily range of the predicted effectiveness is just 5.92%.

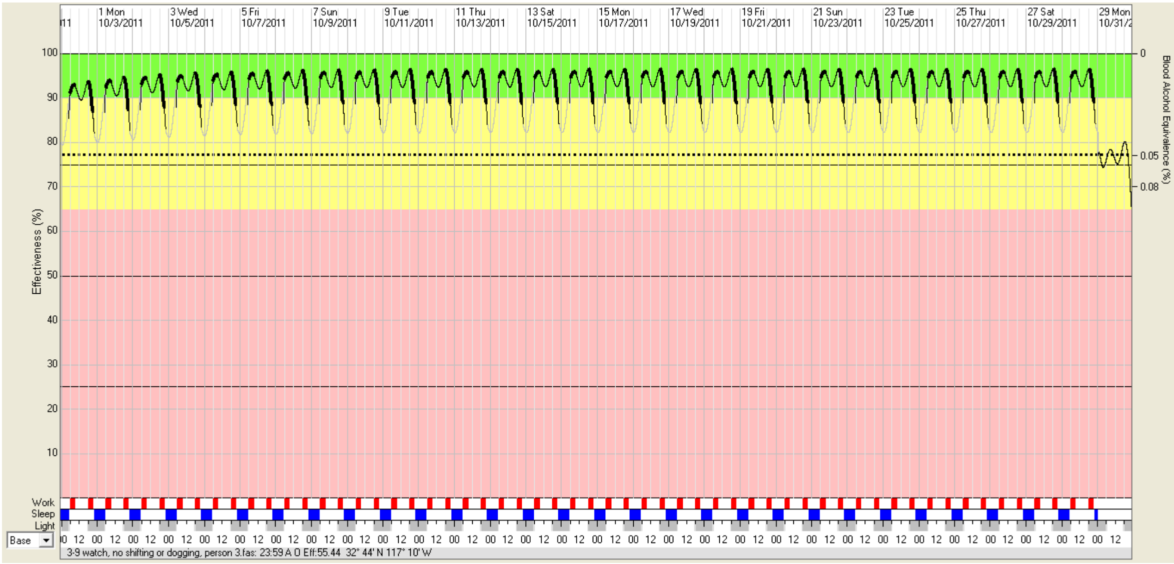


Figure 35. Predicted effectiveness for an individual on the 3/9 watch rotation with no shifting

The data for all watchstanders on the 3/9 watch with no shifting was combined to analyze the overall predicted effectiveness while on watch for all watchstanders. Figure 36 shows a histogram of the predicted effectiveness of all people standing the 3/9 watch with no shifting. Overall, all four people standing this watch have a mean 92.56% predicted effectiveness while on watch, with only 5.8% of the time an individual's predicted effectiveness falls below 80%.

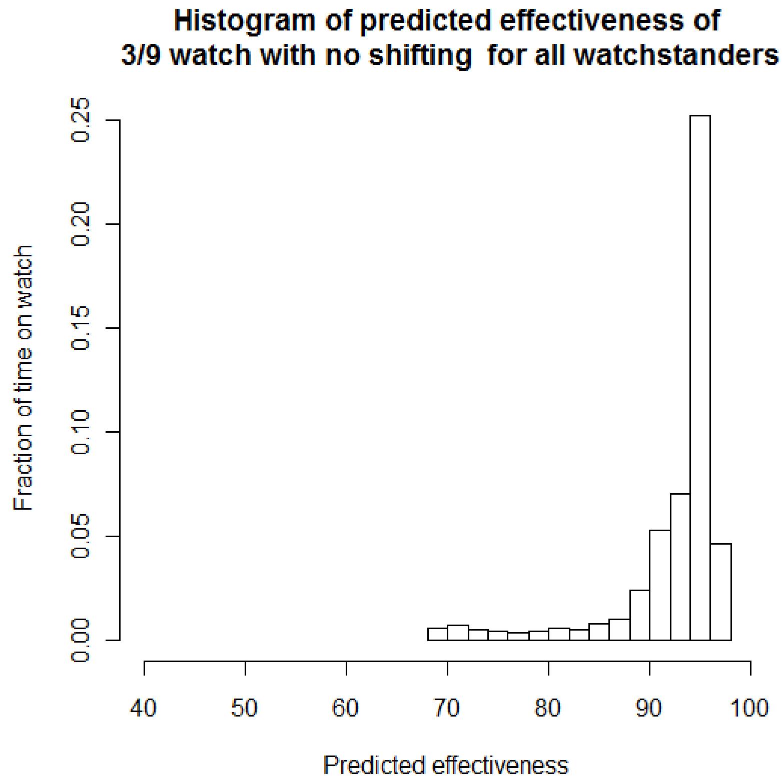


Figure 36. Histogram of predicted effectiveness for all watchstanders on the 3/9 watch rotation with no shifting

In contrast to the high predicted effectiveness of the watchstanders while on watch for the 3/9 schedule with no shifting, the 4/12 schedule shifted back each Sunday has very low predicted effectiveness. Figure 37 shows the predicted effectiveness for an individual standing the 4/12 watch rotation shifting back each Sunday. The predicted effectiveness while on watch is volatile, and spends much of their time below 70%. Below this level the individual's reaction times are slowed, similar to what they would experience if intoxicated since the 70% predicted effectiveness corresponds to a 0.08 BAC level.

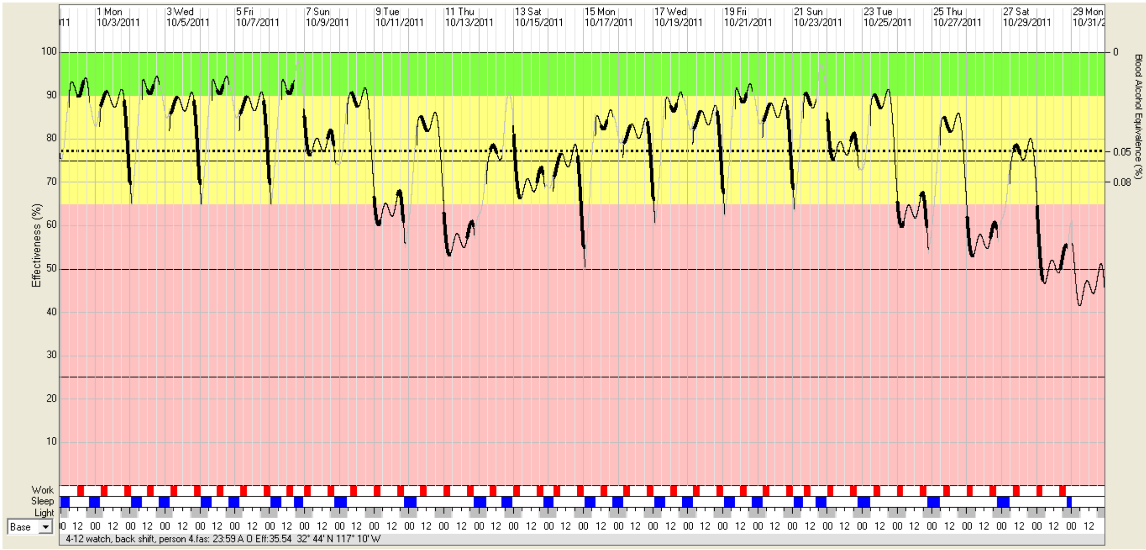


Figure 37. Predicted effectiveness for an individual on the 4/12 watch rotation shifting back each Sunday

The data for all individuals standing the 4/12 watch shifted backwards each Sunday was combined to analyze the overall predicted effectiveness while on watch for all watchstanders. Figure 38 shows a histogram of the predicted effectiveness of all people standing the 4/12 watch shifted backwards each Sunday. Overall, all four watchstanders on this watch have a mean 82.7% predicted effectiveness while on watch, with 33.3% of the time an individual's predicted effectiveness falls below 80%. This is much worse than the 3/9 watch schedule mentioned previously.

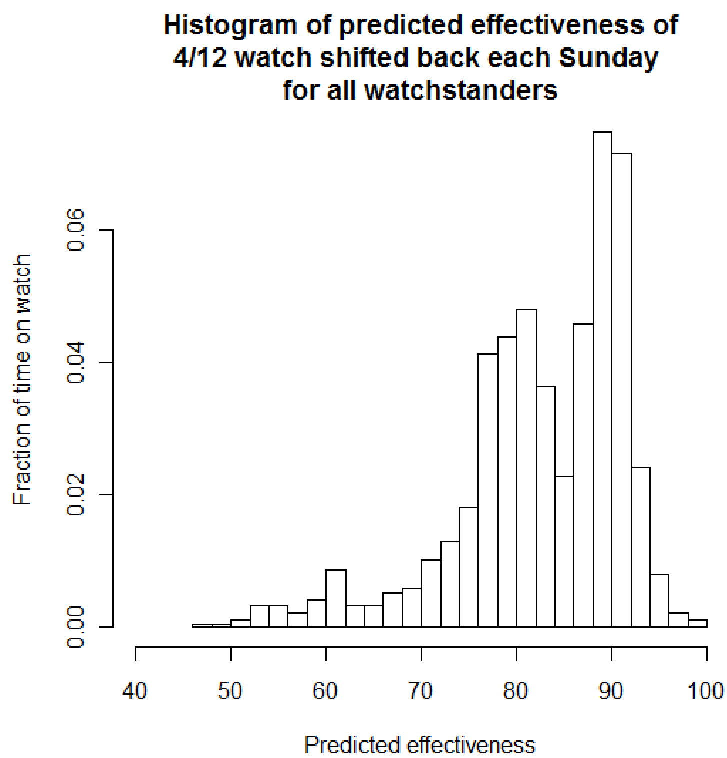


Figure 38. Histogram of predicted effectiveness for all watchstanders on the 4/12 watch rotation shifted back weekly each Sunday

The best watch schedule with no shifting for four section duty is the 3/9 schedule shifted forward each Sunday so no individual stands consecutive watches. This is accomplished by three of the other duty sections standing a longer four hour watch on the Saturday watch to cover for the watch section that has the first shift on Sunday morning. Figure 39 shows the predicted effectiveness for an individual standing the 3/9 watch shifted forward each Sunday so no individual stands consecutive watches. Most of the time the predicted effectiveness while on watch is in the green and yellow sections and above 80% predicted effectiveness.

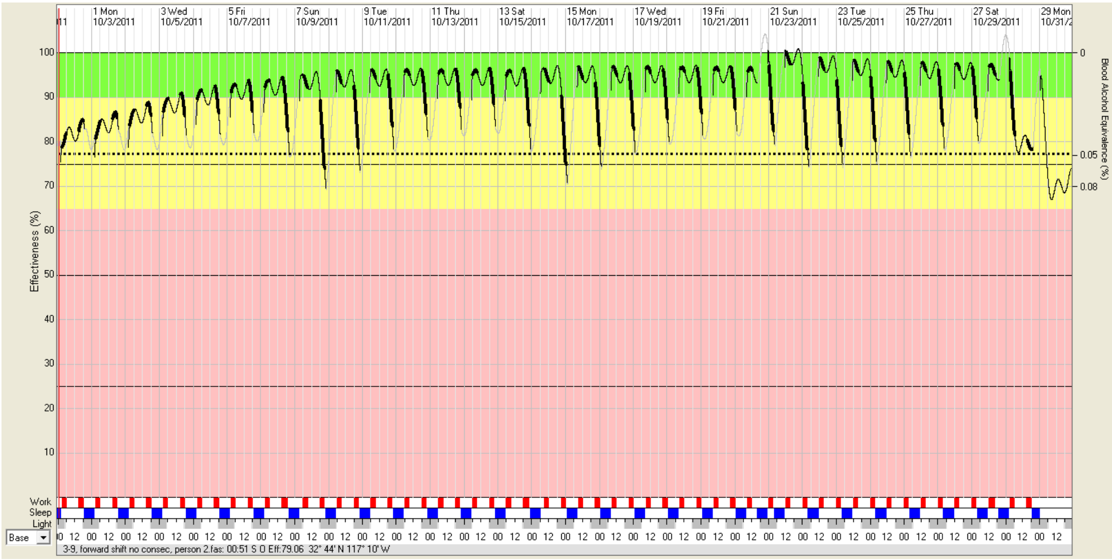


Figure 39. Predicted effectiveness for an individual on the 3/9 watch rotation shifted forward each Sunday with no consecutive watches

The data for watchstanders on the 3/9 watch shifted forward each Sunday with no consecutive watches was combined to analyze the overall predicted effectiveness while on watch for all watchstanders. Figure 40 shows a histogram of the predicted effectiveness of watchstanders on the 3/9 watch shifted forward each Sunday with no consecutive watches. Overall, all three people standing this watch have a mean 88.34% predicted effectiveness while on watch, with 19.7% of the time, an individual's predicted effectiveness falls below 80%. In 6.4% of the time, an individual's predicted effectiveness falls below 70%. The histogram of predicted effectiveness for all watchstanders for the two, three, and four section notional watches analyzed in this thesis are listed in Appendix A for further reference.

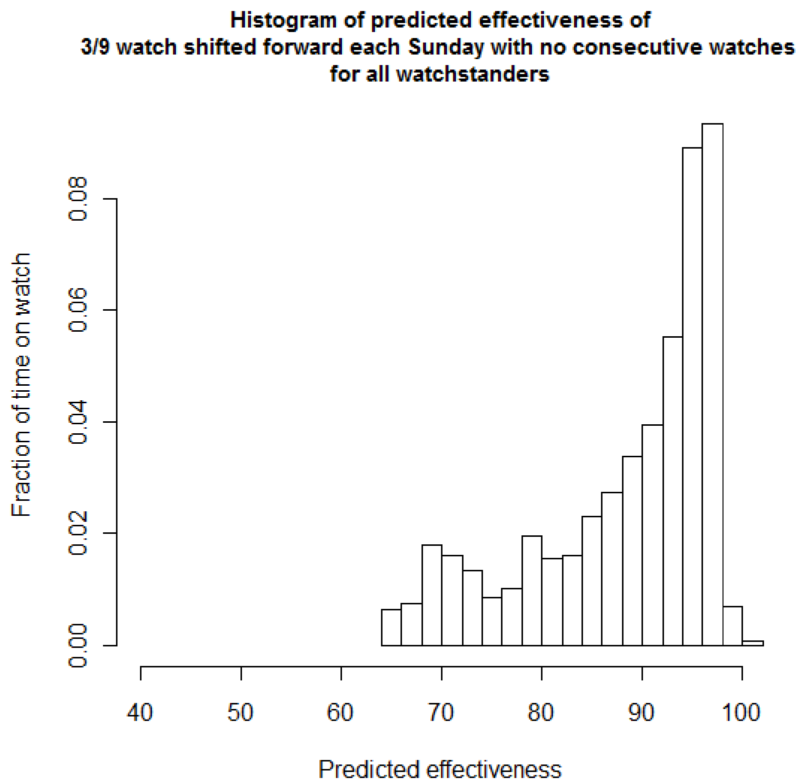


Figure 40. Histogram of predicted effectiveness for all watchstanders on the 3/9 watch rotation shifted forward weekly each Sunday with no consecutive watches

V. CONCLUSIONS AND RECOMMENDATIONS

"Fatigue is the best pillow."

–Benjamin Franklin

A. CONCLUSIONS

1. Analysis of Survey Data

The first objective of this thesis was to analyze the data from a crew survey of the crew of the USS San Jacinto, which compared an alternative watchstanding schedule to more traditional watch schedules. For comparison, the analysis was broken down by enlisted and officers; the alternative 3/9 watch schedule was compared to other watches the crew members had stood in the past. Overall, the crew preferred the 3/9 watchstanding schedule over other types of watch.

Enlisted personnel generally preferred the 3/9 watch and found that each watch type was worse than the 3/9 except for the 5/15 watch. Approximately 60% of enlisted personnel said they received about the right amount of rest or more on the 3/9 watch rotation and said they thought other sailors received about the right amount of rest or more than needed the 3/9 watch rotation. Most of the enlisted personnel said they received more sleep on the 3/9 watch rotation when compared to other watch rotations, except for the 5/15 watch. The open-ended answers by enlisted personnel generally favored the 3/9 watch. Approximately half liked that the 3/9 was a short watch, while one third liked that it was a set or consistent schedule. A minority of the enlisted personnel did not like the odd hours, or thought that there was not enough time off on the 3/9 watch.

Officers preferred the 3/9 watch over other types of watch in a greater proportion than enlisted personnel. All of the officers except for one said they received about the right amount of rest on the 3/9 watch rotation, and two thirds said they thought other sailors received about the right amount of rest or more than needed the 3/9 watch rotation. The open-ended answers by officers also favored the 3/9 watch. Seventy-five percent of the officers liked that the 3/9 watch rotation was a set schedule or consistent, while about half said they had more time to rest and felt that they were more alert. One third of the officers did not like the odd hours on the 3/9 watch rotation, while a minority did not like that there were two watches in one day. A majority of the officers had positive comments about the 3/9 watch rotation, while no officers had any negative comments.

2. Analysis of FAST for Alternative Watch Schedules

The second objective of this thesis was to create and analyze various notional use cases of watch schedules to minimize fatigue and maximize predicted performance while on watch. Notional watch schedules were created for two, three, and four section duty and analyzed using the FAST program. The predicted effectiveness for all people in the watch section was compared.

Some of the watch schedules for three and four section duty incorporated a shifting of the watch. If a watch is not shifted, then the same people stand the same watch each day. Many watchstanders may think this is unfair if they are standing a watch during the late night or early morning hours, so a CO may shift the watch. The shifting typically occurs during the first watch on Sunday morning, and can be shifted forwards or backwards. If the watch is shifted forward, then one duty section is standing back to back watch from the Saturday night before the shift to the shift of the watch section occurring on Sunday. To avoid having one watchstanders stand back to back watches, the other watchstanders can stand a longer watch the Saturday night watch to cover for the watch section which has the first shift on Sunday morning.

a. Watch Schedules with No Shifting

For two section duty, it is not possible to shift the watch with only two watchstanders. When comparing the predicted effectiveness while on watch, it was found that the 12/12 watch was better than the 6/6 and 8-4-4-8 watches. The 12/12 watch had the highest mean, the highest minimum, and highest maximum predicted effectiveness while on watch. Additionally the mean daily range was the lowest, while the percent of time below 70% predicted effectiveness was only 1.5%. Typically a two section duty is never stood unless a ship is severely undermanned. If two section duty is used, the 6/6 (port/starboard) watch is used, which is the worst of the two section watches according to this analysis. The 6/6 does not permit a sailor to receive adequate sleep, while the 12/12 watch does.

For three section duty with no shifting of the watch, it was found that the straight fours watch schedule was the best type of watch when compared to the other types of three section watches that were not shifted. It had the highest mean, the highest minimum, and second highest maximum predicted effectiveness while on watch. Additionally the mean daily range was the second lowest, while the percent of time below 70% predicted effectiveness was only 0.8%. With this watch it is possible for the entire watch section to sleep seven hours per night, and also be up during the day from 0800 to 1600 when normal work and drills occur.

For four section duty with no shifting of the watch, it was found that the 6/18 watch was the best type of watch when compared to the other types of four section watches that were not shifted. The 6/18 watch had the highest mean, the highest minimum, and highest maximum predicted effectiveness while on watch. Additionally the mean daily range was the lowest, while the percent of time below 70% predicted effectiveness was only 1.3%. The 3/9 watch with no shifting had similar performance characteristics to the 6/18 watch. It had the second highest mean, minimum, and maximum predicted effectiveness while on watch. Additionally the mean daily range was the second lowest, while the percent of time below 70% predicted effectiveness was only 1.1%. Since these watches are not shifted, the watchstanders on these watches stand the same watch and sleep the same hours each day, so their circadian rhythm is not adversely affected. Either the 6/18 or 3/9 watch with no shifting is the preferred watch to use for four section duty, but since the performance characteristics are similar for both, the 3/9 watch may be preferred since the watch stander is only standing watch for three hours and would be more attentive than standing watch for six hours.

b. Watch Schedules with Shifting

Overall it was found that shifting the watch forward is better than shifting the watch back, but not shifting the watch results in the best performance characteristics.

If a watch is shifted forward, one person must stand a double watch on the day of the shifting. The watch can be modified as described above by having so no consecutive watches stood, which results in improved performance characteristics for the watch.

For three section duty with shifting of the watch, it was found many of the shifted watch schedules had similar performance characteristics when comparing the mean predicted effectiveness while on watch. Overall the 6/12 watch schedule shifted forward was the best type of watch when compared to the other types of three section shifted watches. It had the highest mean and maximum predicted effectiveness while on watch. Additionally the mean daily range was the second lowest, while the percent of time below 70% predicted effectiveness was 12.9%.

For four section duty with shifting of the watch, it was found that the 3/9 watch shifted forward with no consecutive watches was the best type of watch when compared to the other types of three section watches. The 3/9 watch shifted forward with no consecutive watches had the highest mean, the highest minimum, and highest maximum predicted effectiveness while on watch. Additionally the mean daily range was the lowest, while the percent of time below 70% predicted effectiveness was only 6.4%.

B. COMMANDING OFFICER'S WATCH REFERENCE GUIDE

The CO's watch reference guide (Appendix B) summarizes the research findings from this thesis. It contains various notional use cases of watch schedules for two, three, and four section watches and the predicted performance for each schedule for the watch team while on watch. This guide can be used to help decide which watch schedules to apply given predicted effectiveness levels for the crew that are associated with various watch schedules. Commanding officers can then make more informed decisions while deciding upon a watch schedule for the crew, rather than just relying on traditionally doing what has been done in the past. Using a watch schedule that maximizes the predicted crew effectiveness while on watch means more opportunity for sleep for sailors, less fatigue, a more effective crew, and fewer mishaps.

C. RECOMMENDATIONS

1. Recommendations for U.S. Navy

If there is only enough qualified watchstanders to stand two section duty, the 12/12 watch is recommended since it has the best overall predicted effectiveness while on watch when compared to the other types of two section duty. Watchstanders on this watch stand the same watch and sleep the same hours each day, so their circadian rhythms are not adversely affected. For no shifting of the watch, the straight fours watch schedule is recommended for three section duty, and the 6/18 watch is recommended for four section duty, as these types of watch have the best predicted performance characteristics. If shifting of the watch is used, the 6/12 watch shifted forward is recommended for three section duty, and the 3/9 watch shifted forward with no consecutive watches is recommended for four section duty.

It is recommended that for Commanding officers to make more informed decisions upon watch schedules, that the CO's Watch Reference Guide be distributed to CO's of ships for use in aiding the choice of watch schedule. It is also recommended that the CO's Watch Reference Guide be distributed and briefed to Prospective Commanding Officers (PCO) and Prospective Executive Officers (PEO) at the Navy Command Leadership School. Additionally Command Master Chiefs (CMC) at the Senior Enlisted Academy (SEA) and officers in Department Head School at the Surface Warfare Officer School (SWOS) can be trained on the CO's Watch Reference Guide. The chances for the guide being implemented in the fleet are higher if a greater portion of the senior leaderships on Navy ships is aware of it.

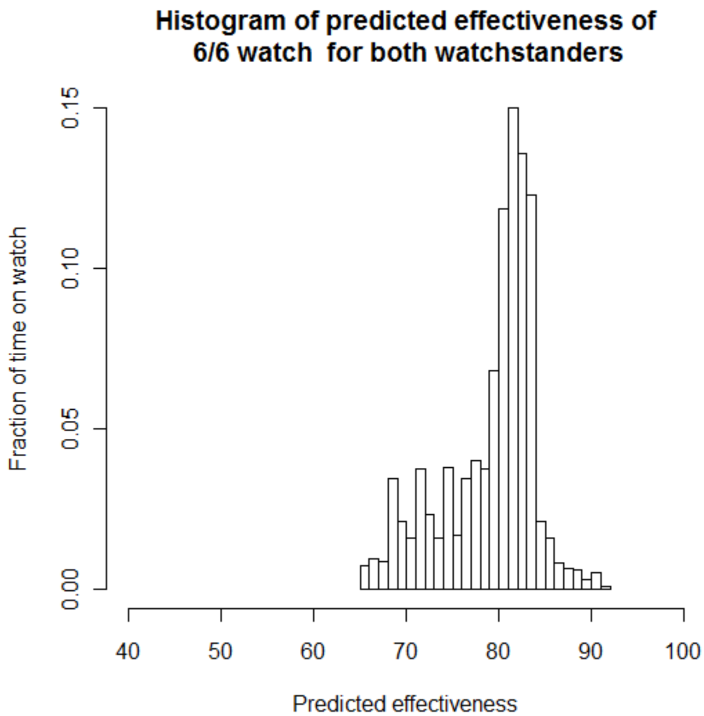
2. Recommendations for Future Work

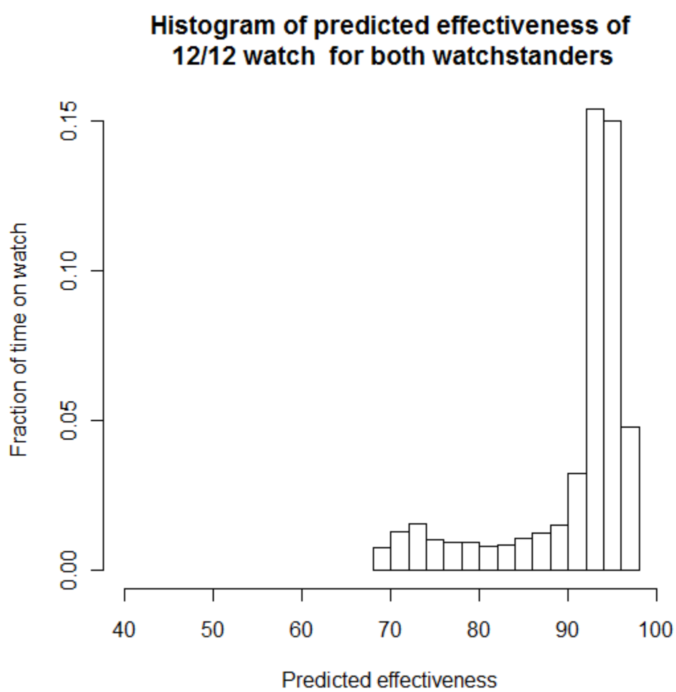
The survey data analyzed for this thesis was the results of only one survey conducted on the crew of the USS San Jacinto (CG 56). The results are the opinion of the crew of one ship in the U.S. Navy, not the entire fleet. It is recommended that a similar survey be conducted and repeated using a larger sample of the overall crew population of the U.S. Navy, using other types of vessels. Testing the 3/9 watch across multiple ships and departments and conducting this survey regarding watch preferences will help determine if the crew preference of the 3/9 watch is dependent upon ship type or department.

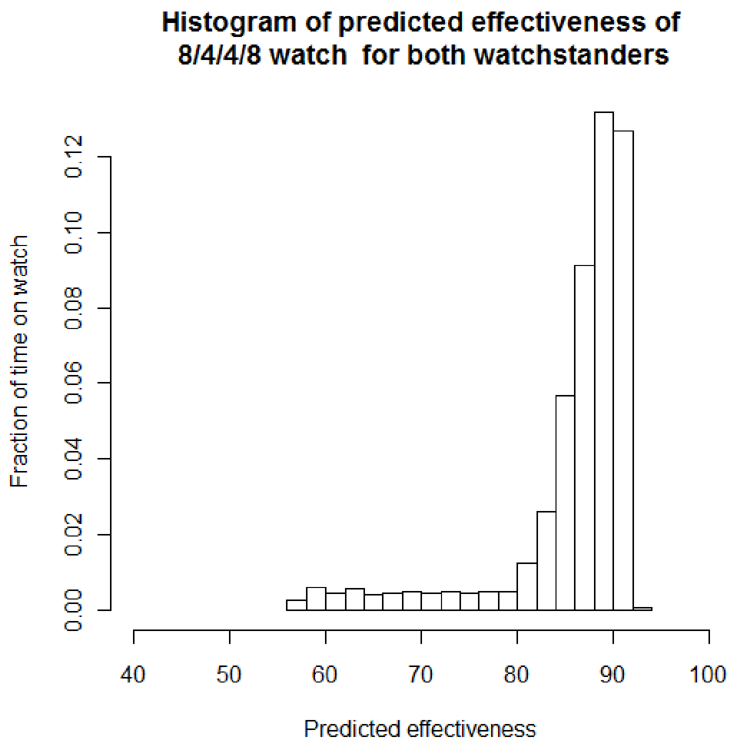
Further research should be conducted on the crew preference of the 3/9 watch, using two ships of the same class, similar crew size, and using four watch sections while on deployment. One ship can be the control group, with the crew standing a standard watch as has done in the past. The second ship can be the experimental group, which will stand the 3/9 watch. Actiwatches can be used to collect sleep data from the crew on both ships, along with a Profile Of Mood States (POMS) test to assess the mood of the crew. Additionally a survey can be conducted on both crews to gauge the preference of the watch, level of sleep received, and other relevant questions. At the end of the deployment the data can be analyzed to further analyze and compare the 3/9 watch to the watch that was stood for the control group.

APPENDIX A

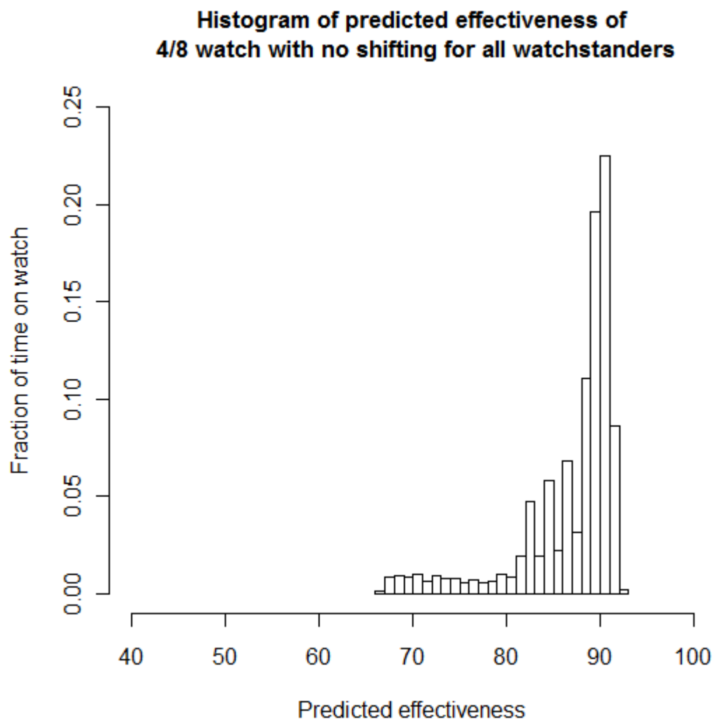
Two Section Watches

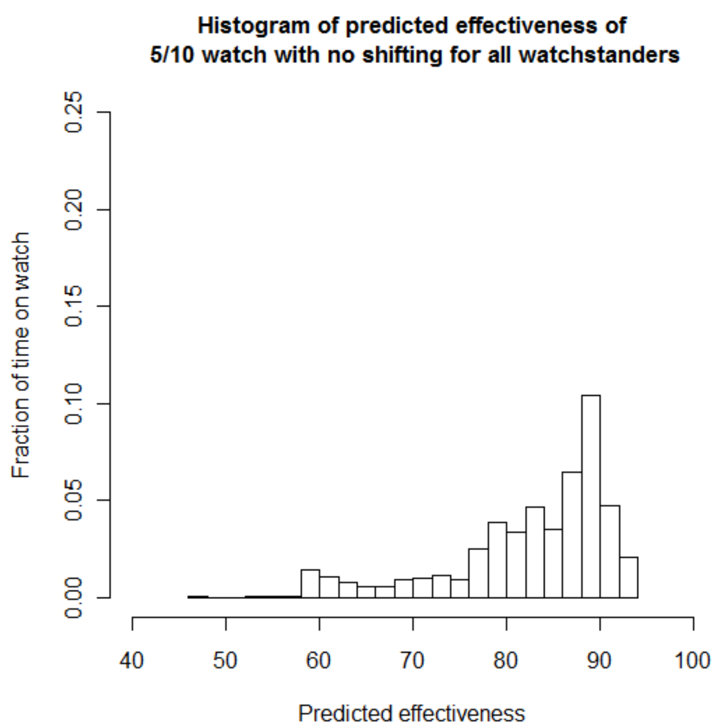


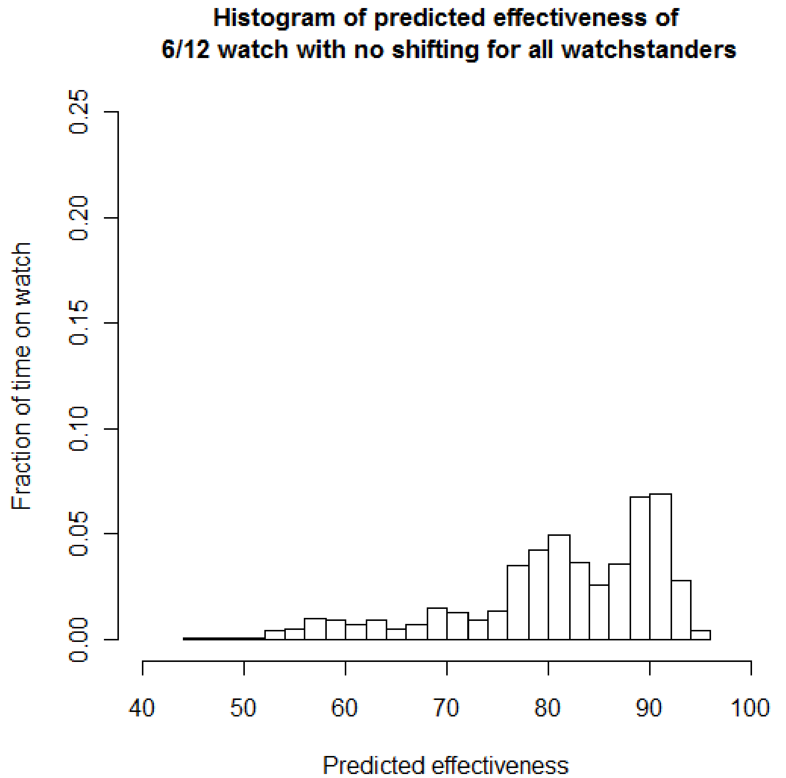



Histogram of predicted effectiveness of
8/4/4/8 watch for both watchstanders
Fraction of time on watch
0.00
0.02
0.04
0.06
0.08
0.10
0.12
40
50
60
70
80
90
100
Predicted effectiveness

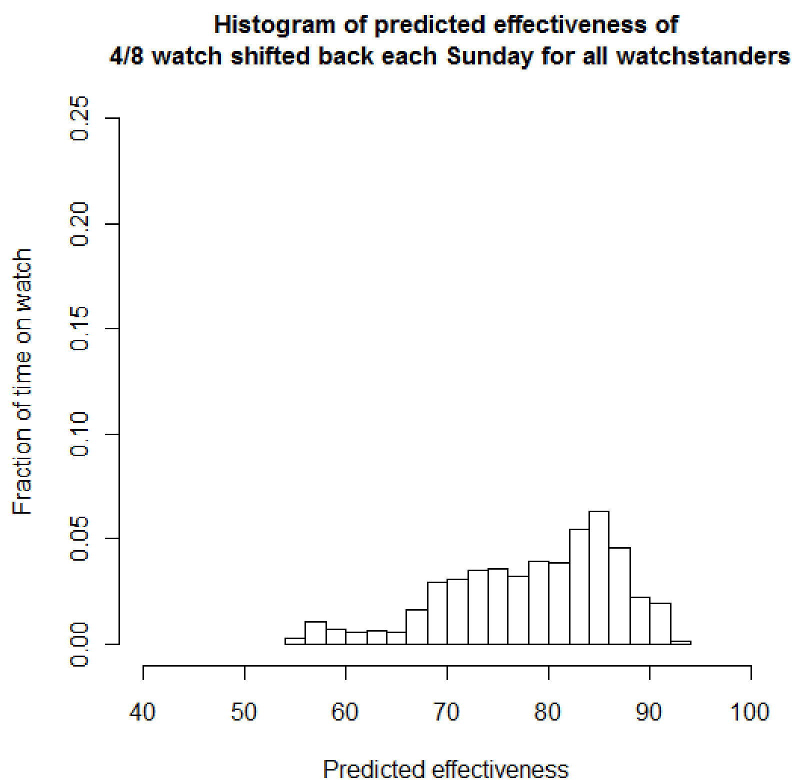
Three Section Watches



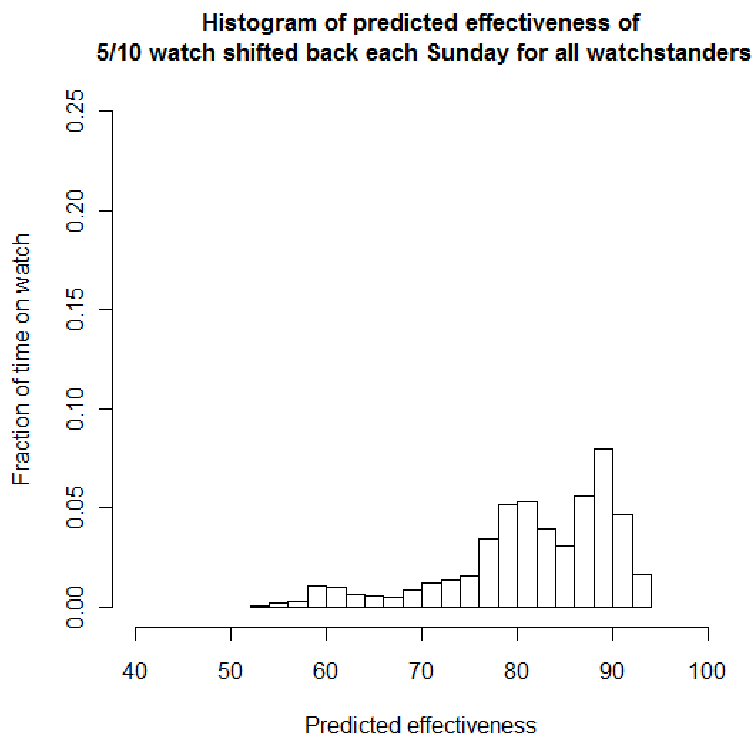


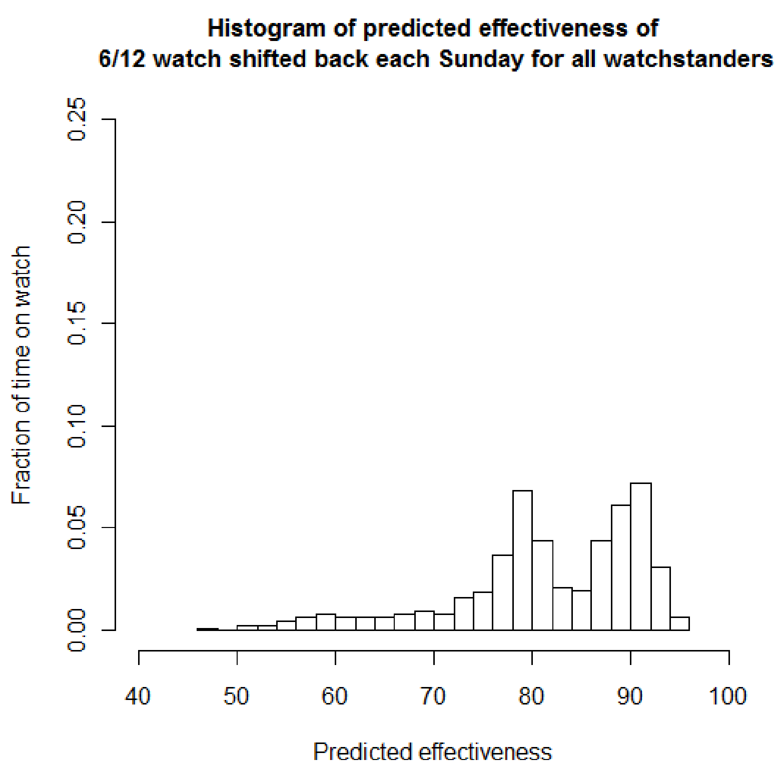


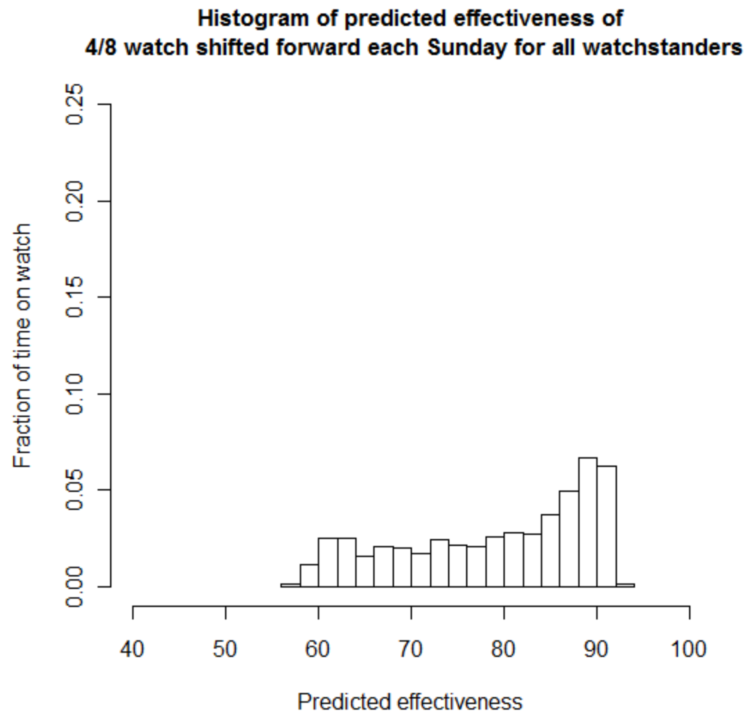
Histogram of predicted effectiveness of
6/12 watch with no shifting for all watchstanders
Fraction of time on watch
0.00
0.05
0.10
0.15
0.20
0.25
40
50
60
70
80
90
100
Predicted effectiveness

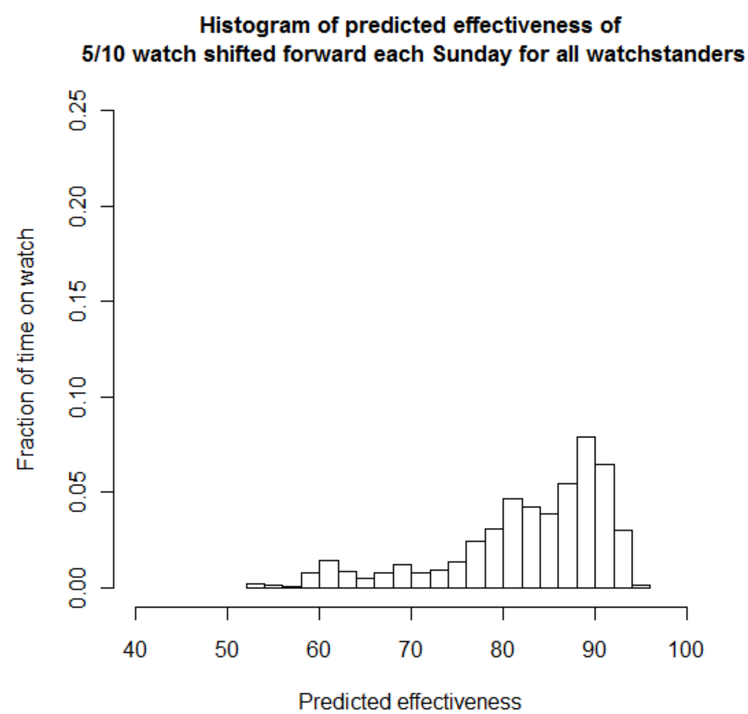


Histogram of predicted effectiveness of
4/8 watch shifted back each Sunday for all watchstanders
Fraction of time on watch
0.00
0.05
0.10
0.15
0.20
0.25
40
50
60
70
80
90
100
Predicted effectiveness


Histogram of predicted effectiveness of
5/10 watch shifted back each Sunday for all watchstanders
Fraction of time on watch
0.00
0.05
0.10
0.15
0.20
0.25
40
50
60
70
80
90
100
Predicted effectiveness


Histogram of predicted effectiveness of
6/12 watch shifted back each Sunday for all watchstanders
Fraction of time on watch
0.00
0.05
0.10
0.15
0.20
0.25
40
50
60
70
80
90
100
Predicted effectiveness


Histogram of predicted effectiveness of
4/8 watch shifted forward each Sunday for all watchstanders
Fraction of time on watch
0.00
0.05
0.10
0.15
0.20
0.25
40
50
60
70
80
90
100
Predicted effectiveness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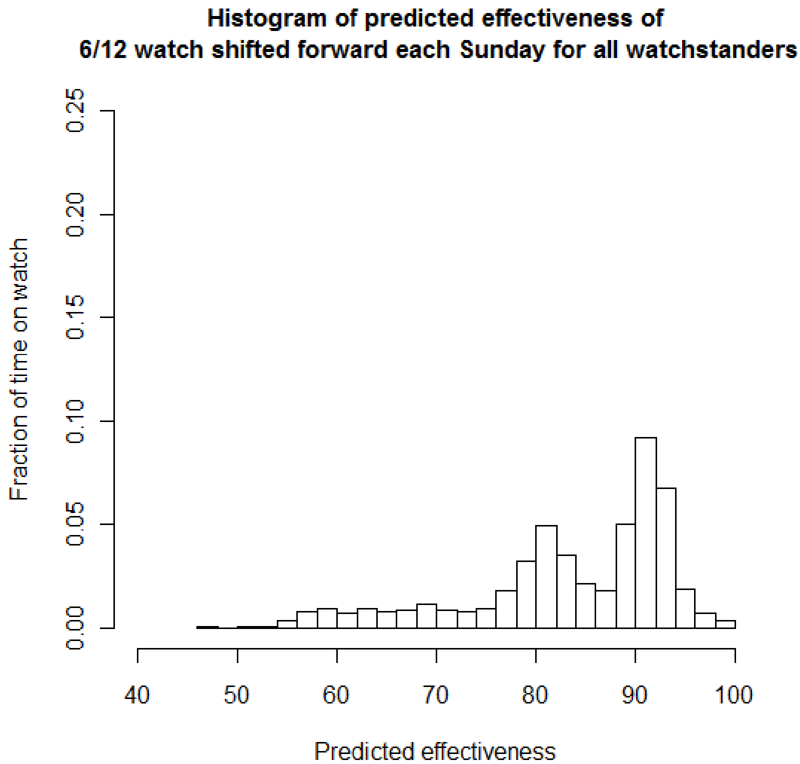
Predicted effectiveness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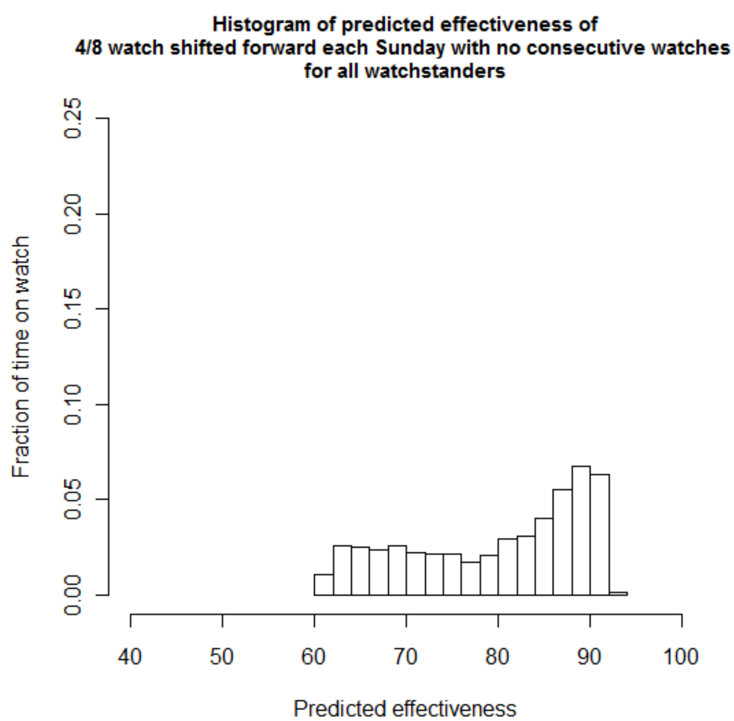
Predicted effectiveness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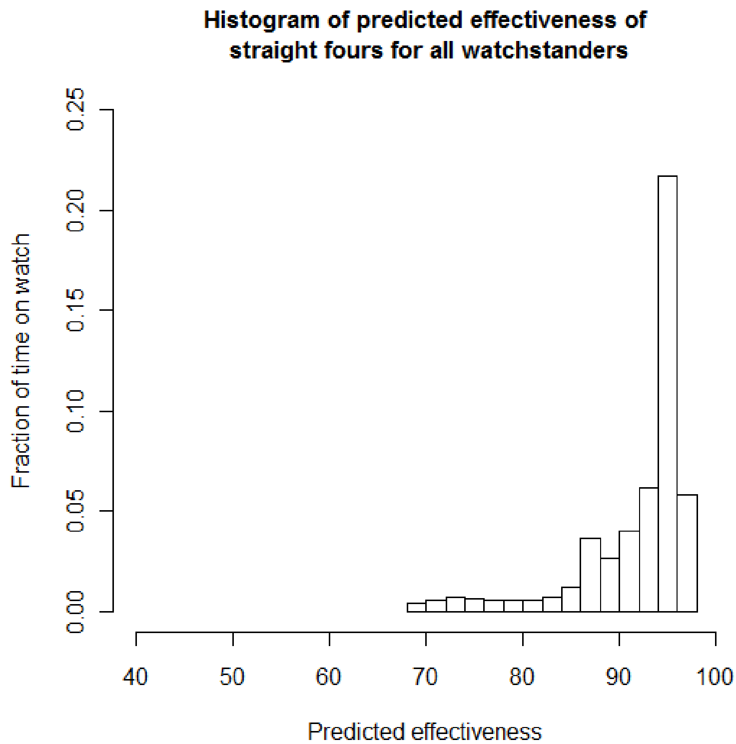
Predicted effectiveness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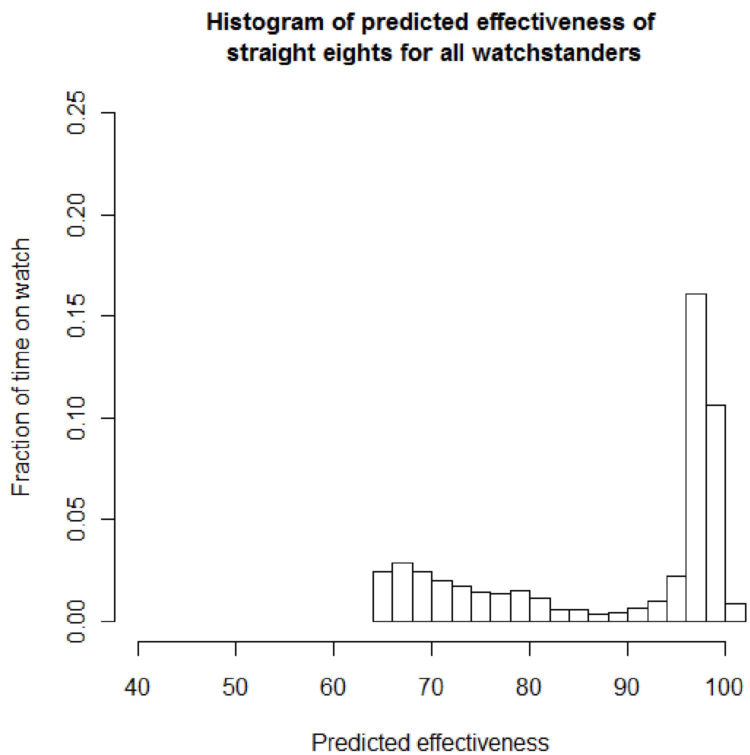
Predicted effectiveness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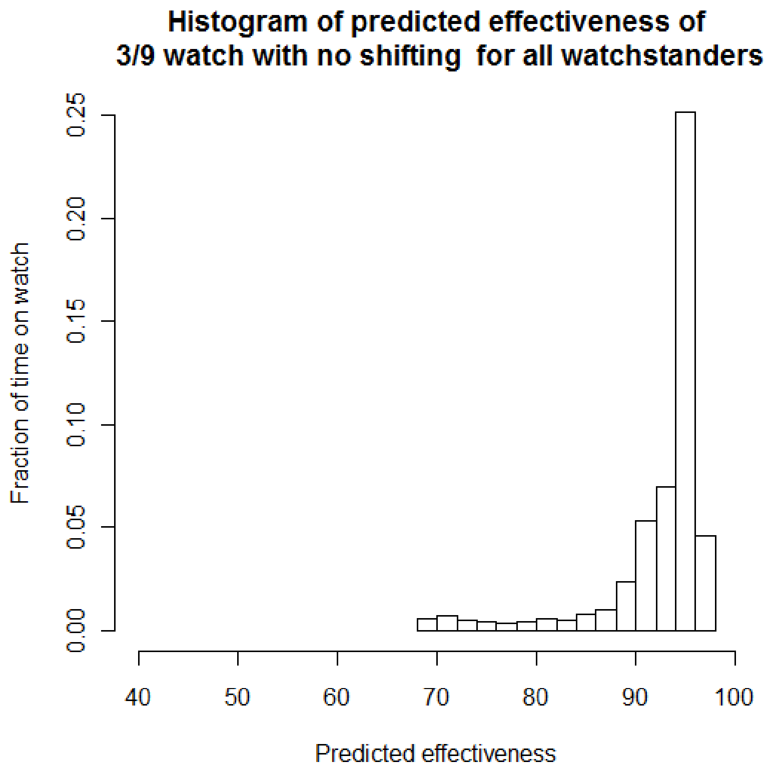
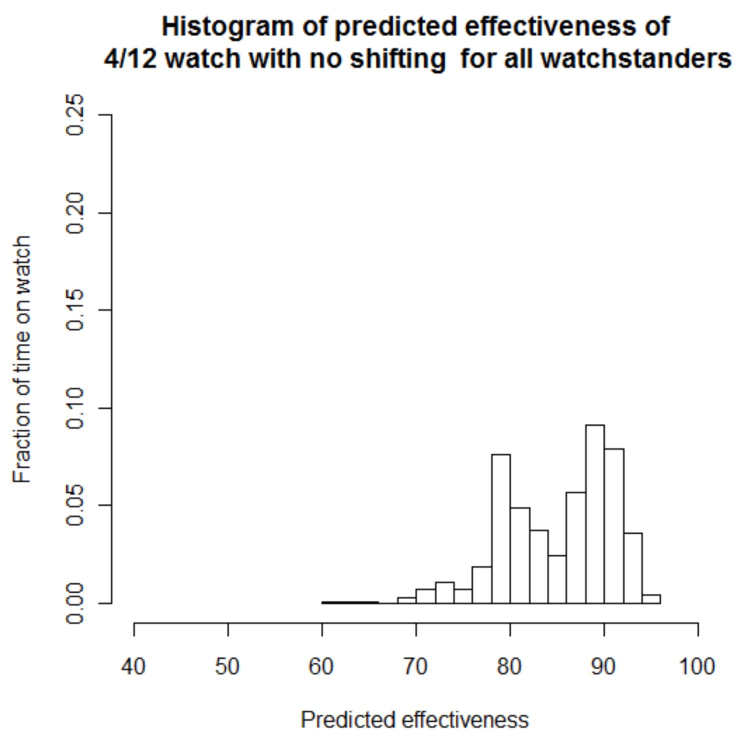
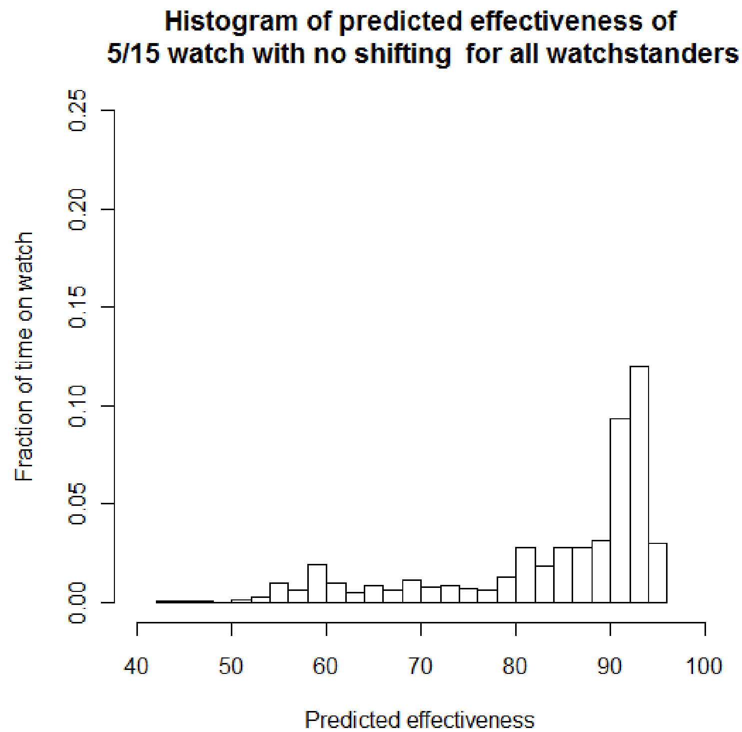
Predicted effectiveness

Four Section Watches







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Fraction of time on watch
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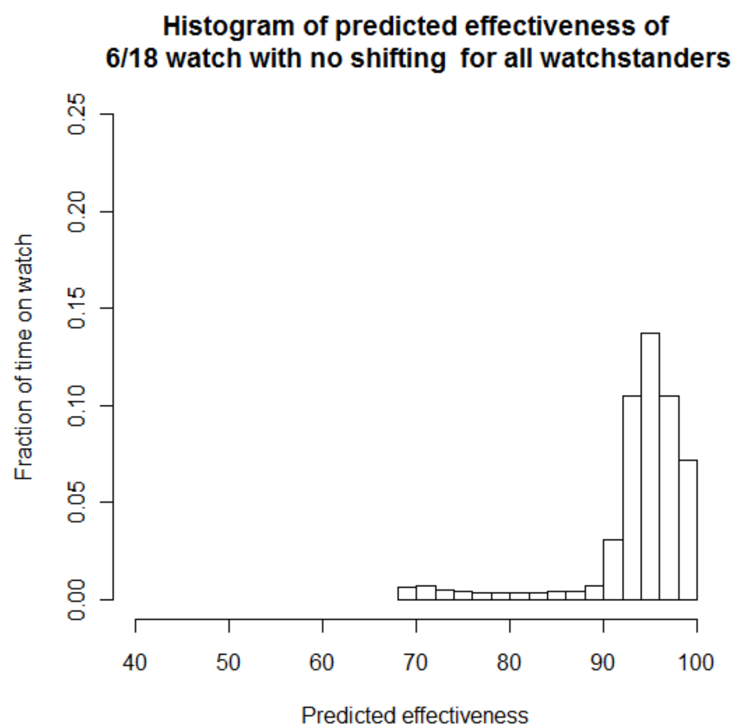
Predicted effectiveness



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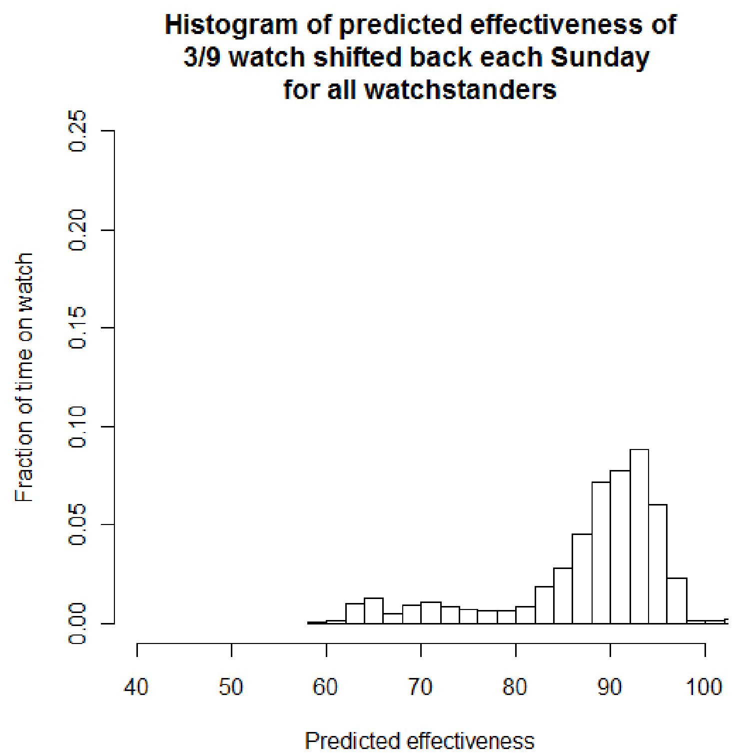
Predicted effectiveness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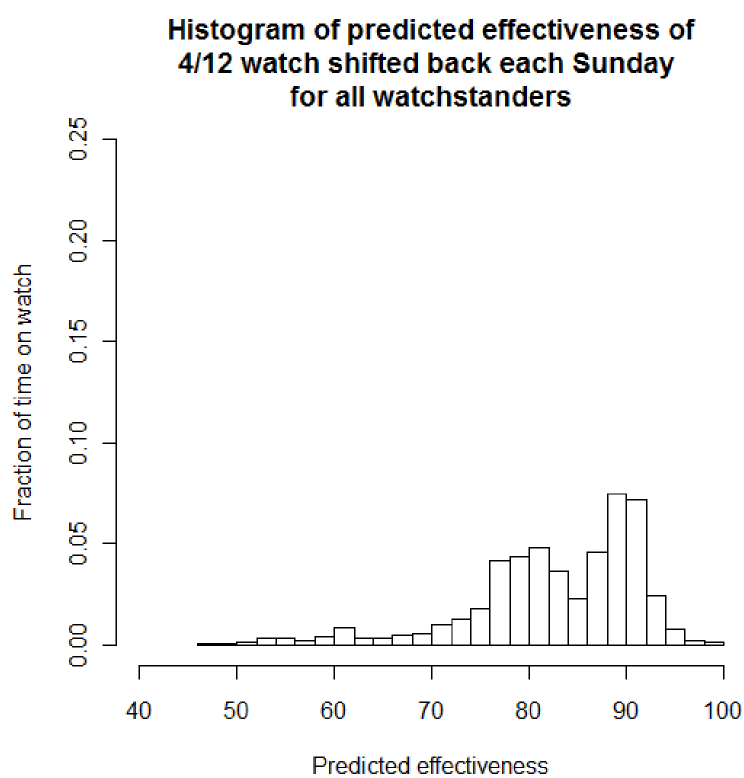
Predicted effectiveness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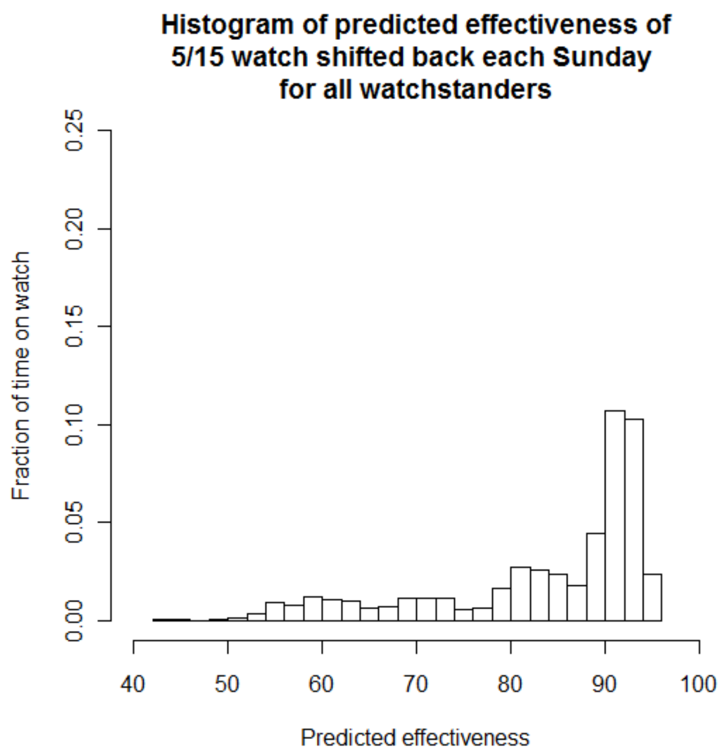
Predicted effectiveness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for all watchstanders
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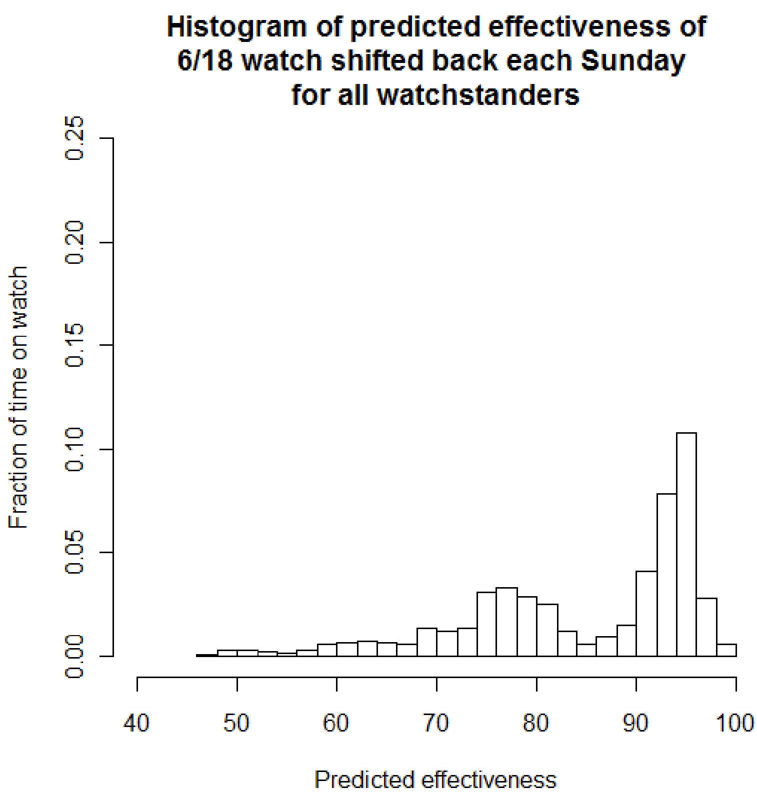
Predicted effectiveness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for all watchstanders
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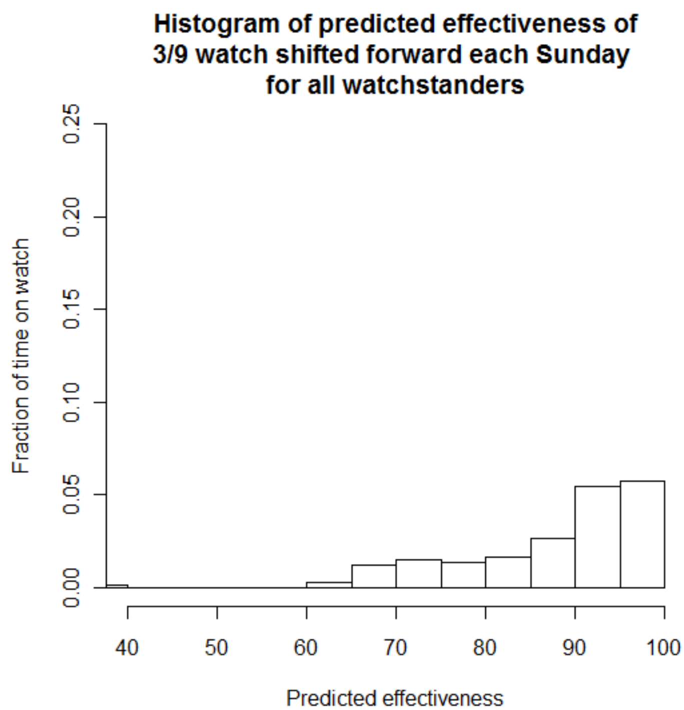
Predicted effectiveness


Histogram of predicted effectiveness of
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for all watchstanders
Fraction of time on watch
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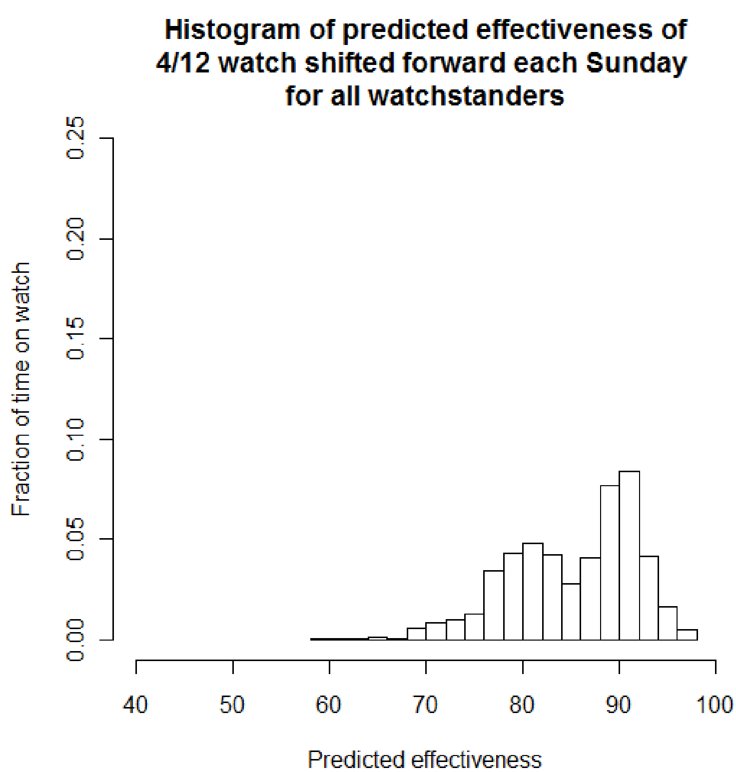
Predicted effectiveness


Histogram of predicted effectiveness of
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for all watchstanders
Fraction of time on watch
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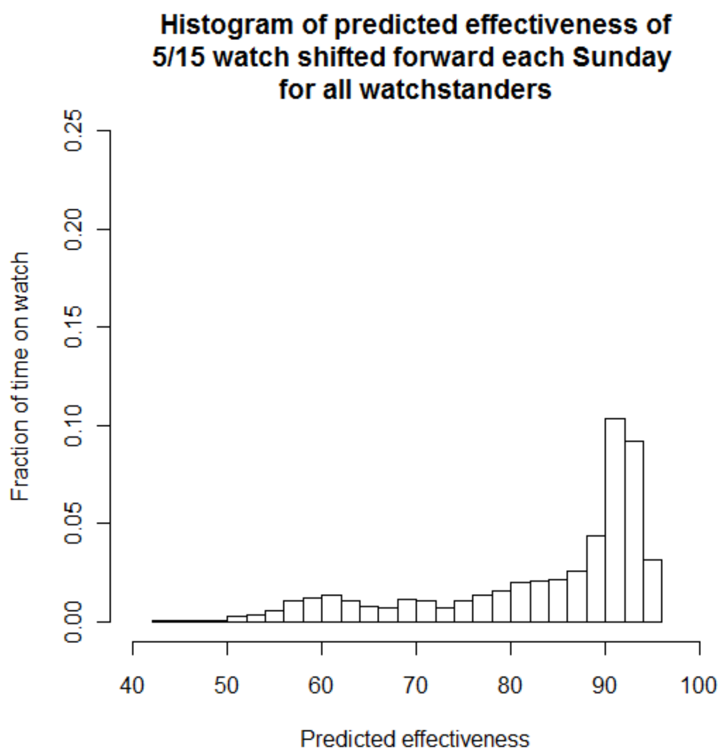
Predicted effectiveness


Histogram of predicted effectiveness of
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for all watchstanders
Fraction of time on watch
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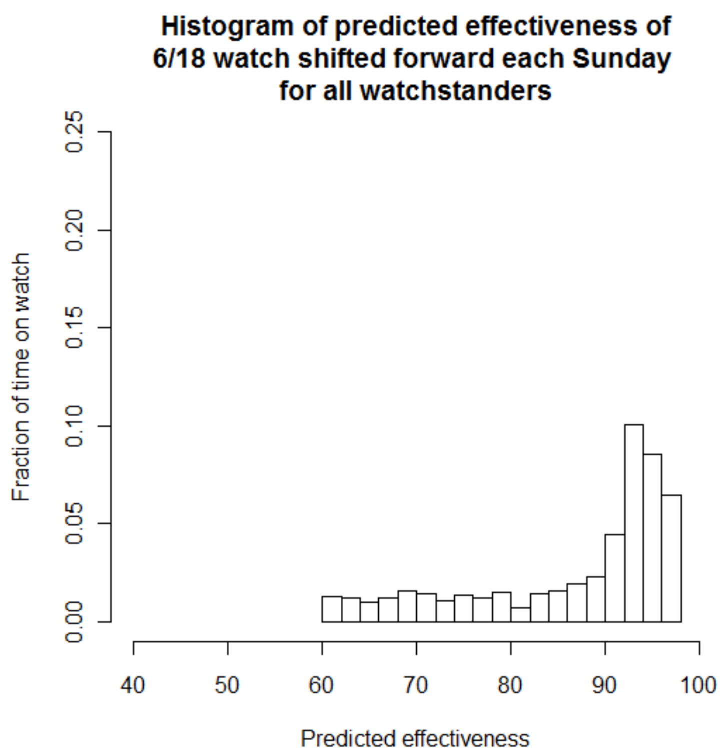
Predicted effectiveness


Histogram of predicted effectiveness of
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for all watchstanders
Fraction of time on watch
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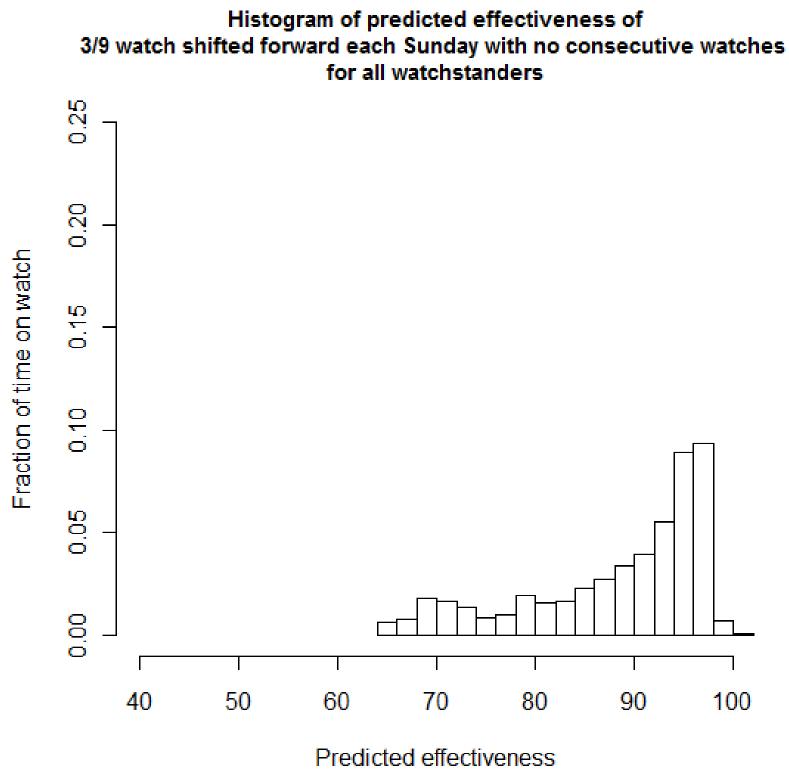
Predicted effectiveness


Histogram of predicted effectiveness of
3/9 watch shifted forward each Sunday with no consecutive watches
for all watchstanders
Fraction of time on watch
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0.25
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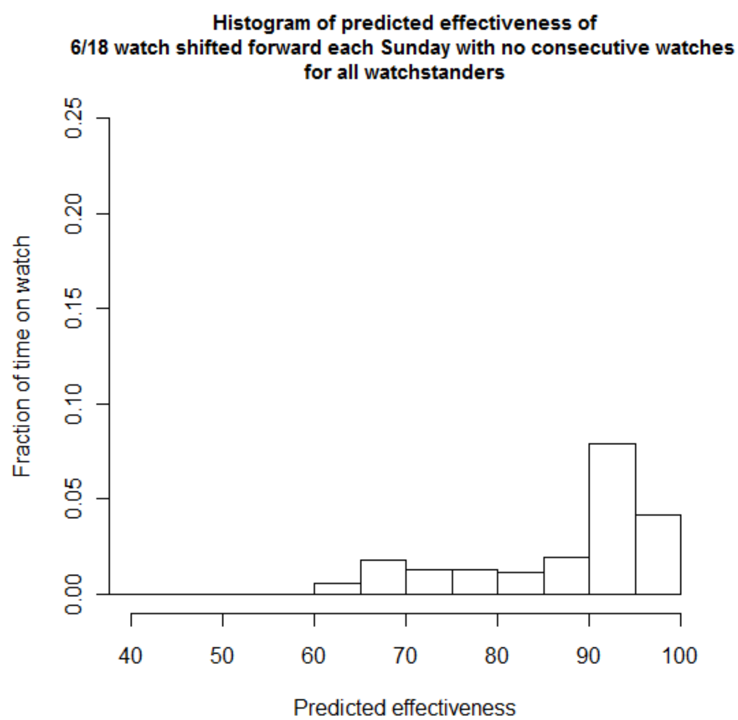
90
100
Predicted effectiveness


Histogram of predicted effectiveness of
6/18 watch shifted forward each Sunday with no consecutive watches
for all watchstanders
Fraction of time on watch
0.00
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Predicted effectiveness

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APPENDIX B

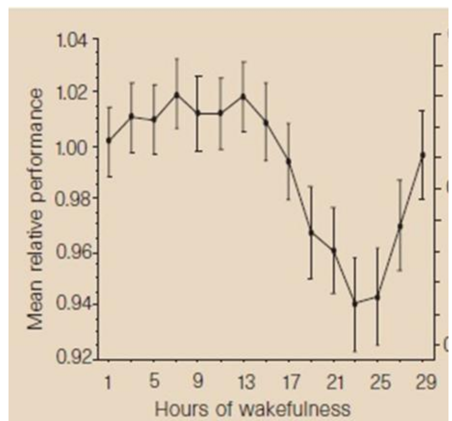
Commanding Officers' Watch Reference Guide

Introduction

This guide summarizes work that has been done to assess watch schedules and identify watchbills that could potentially mitigate fatigue and maximize predicted performance. Scheduling watches on ships in the U.S. Navy has typically been done with little regard for managing the fatigue levels of the watchstanders. Fatigue causes judgment errors and lapses in attention; it is estimated that it is associated with as much as 85% of mishaps caused by human error. Fatigue caused by overwork and lack of sleep is bad for crew morale and thus may play a role in force retention. Using these watch schedules will help to ensure that watchstanders are more alert while on watch.

Sleep and Fatigue

There have been many scientific studies over the years about the effects of sleep deprivation. These studies show various negative behavioral outcomes in people who were deprived of sleep. Effects include difficulty concentrating and communicating, fuzzy reasoning and slowed comprehension, decreased attention, mood changes, and reduced motivation. Memory and creativity are both negatively impacted by sleep deprivation. Good decision-making under uncertain conditions, something commonplace in military operations, is particularly vulnerable to sleep loss. The effects of sleep deprivation have been compared to alcohol intoxication with hours of wakefulness equated to blood alcohol concentration (BAC). Approximately 20-25 hours of wakefulness produced performance decrements equivalent to those observed at a BAC of 0.10%. A BAC of 0.08% is the level at which a person is legally impaired in all 50 states in the U.S.



How to use this guide

Step 1: Determine if there is an appropriate number of qualified watchstanders to stand two, three, or four section duty.

Step 2: Decide if the watch is to remain the same for all watch standers or if it will be shifted each week on Sunday.

Step 3: Select from section below for two, three, or four section duty for shifted or non-shifted watch schedules which have the highest minimum, mean, maximum predicted effectiveness and lowest percent of time below 70% predicted effectiveness

For comparison of various watch schedules, a summary of the predicted effectiveness while on watch is shown for each of the watch types. The comparison tables are sorted by the preferred watches, less preferred watches, and watches to be avoided. The minimum, mean, and maximum of the predicted effectiveness is given for a 30 day watch period averaged for the entire watchstanding team. Since 70% predicted effectiveness corresponds to a 0.08 BAC level, the percent of time spent below 70% predicted effectiveness is of concern because, below this level, the person's reflexes are similar as to if they are legally intoxicated.

Four section duty

For four section duty with no shifting of the watch, the 3/9 watch or the 6/18 watch with no shifting should be used, since these have similar predicted effectiveness while on watch. With no shifting of the watch, a person's work and sleep schedule is set, and their circadian rhythm adjusts to the work / sleep schedule, which minimizes fatigue.

In interest of fairness, the Commanding Officer may want to shift the watch each week. The watch should always be switched forward rather than backwards since shifting the watch forward gives the watchstanders more chance to rest before the next watch, and usually results in a lower mean predicted effectiveness when on watch when compared to if the watch was shifted backwards. If shifting of the watch schedule is implemented, the 3/9 shifted forward weekly on Sunday with no consecutive watches has the highest predicted effectiveness while on watch for the watchstanders.

	Predicted Effectiveness			Percent of time < 70% predicted
Four section duty	Min	Mean	Max	effectiveness
3-9 no shifting	68.24	92.56	97.61	1.1
6-18 no shifting	68.09	93.6	99.71	1.3
3-9 shifted forward weekly on Sunday no consecutive watches	64.23	88.34	100	6.4
4-12 no shifting	60.12	85.12	94.53	0.7
3-9 shifted back weekly on Sunday	59.46	87.5	100	7.7
6-18 shifted back weekly on Sunday	47.41	84.98	99.73	11
3-9 shifted forward weekly on Sunday	35.01	87.45	97.61	8.1
4-12 shifted forward weekly on Sunday	58.56	85.26	97.21	1.8
6-18 shifted forward weekly on Sunday	60.88	86.77	98	1.2
6-18 shifted forward weekly on Sunday no consecutive watches	34.27	87.12	98	11.6
5-15 no shifting	43.95	89.56	95.56	16.3
4-12 shifted back weekly on Sunday	47.74	82.68	99.24	8
5-15 shifted back weekly on Sunday	43.98	83.8	95.79	15.6
5-15 shifted forward weekly on Sunday	43.95	83.4	95.79	17

Four section duty watches: Preferred (green), Less Preferrable (yellow), and To Be Avoided (red).

If the watch is shifted forward for the 3/9 and the 6/18 watches, one person will end up standing a double watch on the Saturday before the watch shift occurs on Sunday. To avoid this, if a watch with shifting is desired, the 3/9 watch shifted forward each Sunday with no consecutive watches should be used. The Saturday before the shift occurs, three watchstanders stand a four hour watch rather than three, and the fourth watchstanders will stand the next watch shifted forward on Sunday morning. Using the 3/9 watch shifted forward each Sunday with no consecutive watches also ensures that all watchstanders are away during the working hours between 0800 and 1600.

Watch before shifting

Time	Work	Sleep			
0100	1		2	3	
0200	1		2	3	4
0300	1			3	4
0400	2			3	4
0500	2			3	4
0600	2				4
0700	3				4
0800	3				4
0900	3				
1000	4				
1100	4				
1200	4				
1300	1				
1400	1				
1500	1				
1600	2				
1700	2	1			
1800	2	1			
1900	3	1			
2000	3	1	2		
2100	3	1	2		
2200	4	1	2		
2300	4	1	2	3	
2400	4		2	3	

Saturday before shifting

Time	Work	Sleep			
0100	1		2	3	
0200	1		2	3	4
0300	1			3	4
0400	2			3	4
0500	2			3	4
0600	2				4
0700	3				4
0800	3				4
0900	3				
1000	4				
1100	4				
1200	4				
1300	1				
1400	1				
1500	1				
1600	1				
1700	2				
1800	2				
1900	2				
2000	2	1			
2100	3	1			
2200	3	1			
2300	3	1	2		
2400	3	1	2		

Sunday shifting of watch

Time	Work	Sleep			
0100	4	1	2		
0200	4	1	2	3	
0300	4		2	3	
0400	1		2	3	
0500	1		2	3	
0600	1			3	
0700	2			3	
0800	2			3	
0900	2				
1000	3				
1100	3				
1200	3				
1300	4				
1400	4				
1500	4				
1600	1				
1700	1				4
1800	1				4
1900	2				4
2000	2	1			4
2100	2	1			4
2200	3	1			4
2300	3	1	2		4
2400	3	1	2		

3/9 watch shifted forward each Sunday with no consecutive watches: this watch is beneficial since no watchstanders will stand consecutive back to back watches after shifting occurs, and all watchstanders are up during working hours between 0800 and 1600.

ec

For three section duty with no shifting of the watch, the straight fours watch should be used in which the watchstanders stands four straight hours of watch with eight hours off. The watchstanders on this watch are up during the working hours from 0830 to 1630, and sleep in the evening or night.

If shifting of the watch is implemented, the 4/8 or 6/12 watch shifted forward weekly on Sunday is the best. The 6/12 has a higher max and mean predicted effectiveness than the 4/8, but also more time spent below 70% predicted effectiveness.

Three section duty	Predicted Effectiveness			Percent of time < 70% predicted effectiveness
	Min	Mean	Max	
straight fours	68.09	91.86	96.93	0.8
4-8 no shifting	66.81	86.75	92.92	2.8
4-8 shifted forward weekly on Sunday	57.43	79.06	92.97	2.4
6-12 shifted forward weekly on Sunday	47.99	83.59	98.33	12.9
5-10 no shifting	46.34	82.54	93.38	1.1
5-10 shifted back weekly on Sunday	53.22	81.69	93.46	10.2
6-12 shifted back weekly on Sunday	47.81	81.67	95.81	11.6
5-10 shifted forward weekly on Sunday	52.05	82.56	94.2	11.6
straight eights	64.5	88.29	100	15.4
4-8 shifted back weekly on Sunday	54.11	78.31	92.97	16.5
4-8 shifted forward weekly on Sunday no consecutive watches	60.55	79.79	97.97	22.2
6-12 no shifting	45.39	81.22	95.75	14.6

Three section duty watches: Preferred (green), Less Preferrable (yellow), and To Be Avoided (red).

Time	Work	Sleep	
0100	Team 1		Team 2
0200	Team 1	Team 3	Team 2
0300	Team 1	Team 3	Team 2
0400	Team 1	Team 3	
0500	Team 2	Team 3	
0600	Team 2	Team 3	
0700	Team 2	Team 3	
0800	Team 2		
0900	Team 3		
1000	Team 3		
1100	Team 3		
1200	Team 3		
1300	Team 1		
1400	Team 1		
1500	Team 1		
1600	Team 1		
1700	Team 2		
1800	Team 2	Team 1	
1900	Team 2	Team 1	
2000	Team 2	Team 1	
2100	Team 3	Team 1	
2200	Team 3	Team 1	Team 2
2300	Team 3	Team 1	Team 2
2400	Team 3		Team 2

The straight fours watch ensures that all watch standers are up between 0830 and 1630, and also ensures that all watchstanders get at least seven hours of sleep each night.

Two section duty

With only two people to stand watch, there are not that many watch schedules available. Two section duty should be avoided as it has the lowest predicted effectiveness when compared to three and four section duty. If it is to be used, the 12/12 watch is the best when compared to the alternatives. Watchstanders on this watch stand the same watch and sleep the same hours each day, so their circadian rhythms are not adversely affected.

Two section duty	Predicted Effectiveness			Percent of time < 70% predicted effectiveness
	Min	Mean	Max	
12-12 watch	68.09	90.61	97.05	1.5
8-4-4-8 watch no shifting	56.89	85.92	92.04	6.3
6-6 (port / starboard watch)	65.56	79.19	91.34	8

Two section duty watches: Preferred (green), Less Preferrable (yellow), and To Be Avoided (red).

Further Questions

This CO's Watch Standing Guide was completed as part of a Master's thesis by LT Donald Roberts at the Naval Postgraduate School in March 2012. To obtain a copy of this thesis for further reference, or for any other questions, contact Dr. Nita Shattuck at: nlshattu@nps.edu

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