Exh. IC-15
TP-190976

Puget Sound Pilot Fatigue Study Report

Kevin Gregory, B.S., Nicholas Bathurst, M.A., Cassie Hilditch Ph.D.

San Jose State University Research Foundation
Ames Research Center
Moffett Field, CA, 94035

Erin Flynn-Evans, Ph.D., MPH

National Aeronautics and Space Administration
Fatigue Countermeasures Laboratory
Ames Research Center
Moffett Field, CA, 94035

Table of Contents

Maritime pilot: "… a mariner with expert knowledge of local waters and special ship handling skills. The pilot directs and controls the movement of a vessel through near-shore and inshore waters (referred to as pilotage waters or pilot grounds) unfamiliar to the master or provides navigation advice to or through the master for this purpose. The pilot is expected to integrate local knowledge with operational information to effect a safe passage."

(*Minding the Helm: Marine Navigation and Piloting*, 1994)

1 Glossary

Term	Description
Assignment	A duty period including vessel movements, repositions, upgrades, meetings, and training
Calendar year analysis	The one-year period between January 1, 2018 and December 31, 2018
Callbacks	Work shifts where pilots are called to work at times when they were off call.
Call time	The time when a pilot is given an assignment.
Check-in time	The end of a work assignment.
Circadian low	The point in the circadian rhythm associated with lower body temperature, reduced alertness, reduced cognitive performance, and increased drive for sleep. It typically occurs between 0100-0600 in individuals who are entrained to the light-dark cycle of their local environment.
Circadian rhythm	The rhythmic 24-hour variability of certain behavioral and physiological functions (e.g., sleep/wake cycle, body temperature).
Compensation days (‘comp’ days)	Days off accrued by the pilots for days worked during off call periods.
Work period/duration	The duration of time from the call time until the check-in time.
Fatigue	A biological drive for recuperative rest.
Job start time (job time)	The time when the pilot boards a vessel.
Completion time	The time when the pilot disembarks a vessel.
Multiple harbor shift (MHS)	A series of harbor moves completed by a single pilot during one work period.
Off-watch	The 13-day period during which a pilot is not available for pilotage.
On-watch	A week or weeks during which a pilot is available for work at any time.
Rest period	The period from check-in time to call time.
Reposition (‘repo’)	An assignment that involves moving a pilot from one location to another in order to position pilots in a location appropriate for completing vessel movements.
Skill fatigue	The degradation in skilled performance that can occur after sustained periods of intense concentration.
Sleep apnea	A medical condition in which the upper airway is obstructed during periods of sleep, resulting in intermittent hypoxia, episodic arousals, and sleep fragmentation.

Sleep debt	The deficit between the amount of sleep needed and the amount of sleep obtained. Sleep debt can accumulate over multiple nights, producing progressively more severe performance impairment.
Sleep inertia	The “grogginess”, “disorientation”, and associated performance impairments experienced upon waking.
Trailing 12 months	The 12 month period from October 2017 until the end of September 2018
Upgrade	A vessel move assignment completed by a pilot in order to upgrade his/her pilot license.
Work period	The period from the call time to the check-in time.

2 Structure of this document

This document begins with an introduction to the topic of fatigue, its causes, and its impact on human performance. The work of Puget Sound Pilots (referred to simply as “pilots”) is then described. We then review the literature on fatigue in transport and industry, including prior studies of maritime pilots. We next present our two primary data analysis efforts 1) descriptive statistics summarizing factors likely to influence fatigue, including questions posed by the Board of Pilot Commissioners Fatigue Management Committee based on 12 months of dispatch data that was provided to us by the pilots, 2) a model estimating staffing requirements to account for the assignment level and adherence to fatigue risk management policies. Following a final summary and conclusions section, we list a series of recommendations intended to assist the Puget Sound Pilots as it develops mitigation systems and regulations to manage the risk of pilot fatigue.

3 Background

The Puget Sound Pilots

In 1789, the US Congress passed the Lighthouse Act to provide the legal framework of maritime piloting (Hobbs et al., 2018). Over a century later, the Puget Sound Pilots (PSP) were established. The first record of pilotage on the Puget Sound was made in 1840 and the hazards and risks of the job are largely the same now as they were at that time (Smith, 2014). The PSP are licensed for 52 highly skilled independent professional contractors authorized by the Washington Board of Pilotage Commissioners (BPC) to safely pilot container ships, oil tankers, cargo vessels, and cruise ships through Puget Sound waters. On average, there are more than 7,000 pilot driven ship movements per year in the Puget Sound. The mission of the Puget Sound Pilots is to safely pilot vessels through the Puget Sound in order to prevent loss of lives, damage to property and vessels, and harm to the marine environment ("Puget Sound Pilots," 2019).

The Puget Sound waterway is bordered by the Olympic Mountain Range to the West, Canada to the North, Tacoma to the South, and Seattle to the East (Figure 1). Puget Sound includes 7,000 square miles of waterway, 14 major ports and two dispatch hubs (i.e., Port Angeles Pilot Station and Seattle) ("Puget Sound Pilots Website," 2019). The geographical location of Puget Sound can produce extreme and unpredictable weather conditions and waterway changes when compared to other ports around the US (*Washington state pilotage final report and recommendations*, 2018). For example, fog, storm cells moving directly through the sound, and drastic changes in tides and currents complicate navigation of ship traffic through the Sound.

The Puget Sound Pilots service vessels using a “board-on-arrival” model of service, where a pilot is dispatched to guide a ship through the Sound upon arrival in the waterway or as requested for departure or other ship movements. In order to provide board-on-arrival service, the pilots work an on-call watch schedule, where half of the licensed pilots are scheduled for 15 consecutive days on at a time. During the on-watch period, pilots may be called to board a vessel at any time of day or night. The pilots available for work on a given watch are assigned work by dispatch in a rotation, whereby after a pilot completes a vessel move, s/he will be moved to the bottom of the watch list and will not be assigned another assignment until all available qualified pilots on the list have been assigned work. Ship traffic is monitored, and projected arrival times are reviewed by dispatchers, but a variety of factors can influence the actual arrival time relative to the scheduled arrival time. The unpredictable nature of the rotation of pilots, coupled with unpredictable ship arrival times leads to irregular and unpredictable schedules. Adding to these challenges, the border with Canadian waters and differences between maritime operations in the two countries can reduce the predictability of ship arrivals. Ship traffic is only allowed to the ports in British Columbia during specific windows of time. If a Canada-bound ship misses a window, then they will go to the Puget Sound. (Communication from the President of the Puget Sound Pilots, September 14, 2018). A consequence of irregular schedules and the unpredictable nature of PSP operations introduces the concern that pilots may not be able to obtain sleep of adequate quantity and quality. Such sleep deficiency increases the risk of performance impairment.

As a result, the goal of the current study was to evaluate one year of PSP dispatch records to identify potential areas of concern, to recommend work hour changes based on any issues identified, and to determine how many pilots should be licensed in order to continue board-on-arrival service, while also minimizing the impact of fatigue.

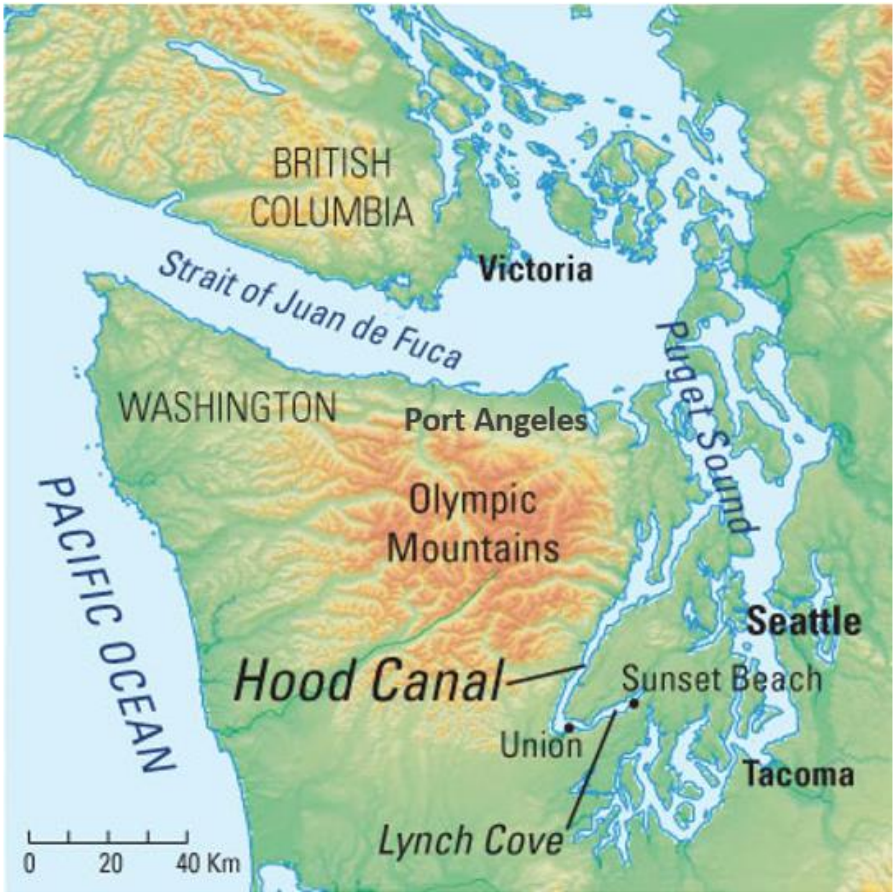


Figure 1. Map of the Puget Sound waterway.

Causes and Consequences of Fatigue

Fatigue is a major threat to safety in industries that require irregular schedules and 24-hour operations with numerous incidents and accidents being attributed to fatigue (Mitler et al., 1988). Indeed, in approximately 20% of incidents investigated by the National Transportation Safety Board (NTSB) over a 12-year span, fatigue was implicated as a causal factor (Marcus & Rosekind, 2016). The reduction of fatigue-related accidents in all transport modalities and a requirement for medical screening and treatment for sleep apnea are both included on the NTSB's list of ten "most wanted" safety priorities.

3.1.1 Definition of Fatigue

This report will use the term fatigue to describe changes in alertness and cognitive performance arising from sleep loss, circadian misalignment, and sleep inertia. Each of these factors are described in detail below. We recognize that the term fatigue can be used to describe other conditions, such as physical discomfort stemming from muscle exertion and degradation of performance due to elevated workload or sustained mental focus. While these forms of fatigue may degrade performance, they are difficult to quantify and are outside the scope of this report.

3.1.2 Sleep and Circadian Rhythms

The drive for sleep is regulated by two processes: homeostatic sleep pressure and the circadian rhythm. Homeostatic sleep pressure builds up with hours of wakefulness and is dissipated by time spent asleep. Therefore, the longer an individual is awake, the higher sleep pressure will be. The circadian rhythm is often referred to as the body clock. It typically promotes sleep at night and wakefulness during the day. When an individual obtains regular, nighttime sleep opportunities, these two processes interact to promote consolidated sleep at night (Dijk & Czeisler, 1994). Under these optimal conditions, homeostatic sleep pressure builds up across the day until sleep onset. In order to maintain wakefulness until bedtime, the circadian rhythm in alertness is highest in the hours just before regular bedtime, counteracting the high sleep drive until it is time to sleep. As bedtime approaches, the circadian rhythm starts to promote sleepiness which, in combination with a high homeostatic drive, initiates sleep. As sleep pressure dissipates throughout the sleep episode, the circadian rhythm in alertness drops to its lowest level in the last third of the sleep episode in order to promote a consolidated bout of nighttime sleep. Perturbations to this balanced interaction can lead to sleep loss and fatigue, as described below.

3.1.3 Acute Sleep Loss

Acute sleep deprivation arises from spending too many continuous hours awake, i.e., increasing the homeostatic sleep drive past the regular threshold for sleep (Dijk & von Schantz, 2005). Laboratory studies have shown that as hours of wakefulness increase past 16 hours, cognitive performance rapidly degrades (Dijk, Duffy, & Czeisler, 1992) with sustained wakefulness of 18 hours leading to performance decrements equivalent to having a blood alcohol concentration of 0.05%, the legal drink drive limit in several countries (Dawson & Reid, 1997).

Acute sleep loss can also be referred to as extended wakefulness and is common in shiftwork environments with long shifts or irregular schedules that make it difficult to plan pre-shift sleep. For example, prior to a night shift, it is often difficult to sleep during the daytime. Therefore, workers are often awake for more than 24 hours at the end of the night shift. This first night shift is associated with impaired performance (Santhi, Horowitz, Duffy, & Czeisler, 2007). Furthermore, working overtime and extended shifts is associated with a higher rate of injuries and accidents (Barger et al., 2005; Lombardi, Folkard, Willetts, & Smith, 2010).

3.1.4 Chronic Sleep Loss

Recent consensus statements from the National Sleep Foundation and American Academy of Sleep Medicine suggest that adults need 7-9 hours of sleep per night for optimal alertness during the day (Hirshkowitz, 2015; Watson et al., 2015). If an individual obtains as little as two hours less sleep than they need each night, this sleep debt can accumulate leading to chronic sleep loss and impaired performance (Belenky et al., 2003; Van Dongen, Maislin, Mullington, & Dinges, 2003). With each additional night of reduced sleep, performance will be worse than it was the day before. Indeed, chronic sleep loss can have impacts on performance that are as severe as those from acute sleep loss. For example, following sleep restriction of a six-hour opportunity per night across 10 days, performance impairment was degraded to the equivalent of one whole night of sleep loss (Van Dongen et al., 2003).

Despite sleep duration recommendations, work and life demands, poor sleep hygiene and sleep disorders result in most adults obtaining less sleep than they require, with nearly 30% of the US population reportedly obtaining six or fewer hours of sleep per night (Krueger & Friedman, 2009; Luckhaupt, Tak, & Calvert, 2010). Further, several studies have demonstrated that airline pilots, truck drivers, and heath care providers working non-standard hours regularly obtain two or three hours less sleep than their optimal daily requirement (Rosekind, 2005). Analysis of time-use data reveals that work and sleep time are inversely related (Basner & Dinges, 2009), suggesting that work schedules can be a primary cause of sleep loss. In addition, fatigue has been shown to increase with the number of consecutive shifts (Folkard, Lombardi, & Tucker, 2005), especially across consecutive night shifts (Aisbett & Nichols, 2007).

3.1.5 Circadian Misalignment

Sleep timing, along with many other physiological processes, is coordinated by a biological clock that operates on a near-24-hour daily (circadian) cycle (Czeisler & Gooley, 2007). In order to align the circadian rhythm with the 24-hour solar light-dark cycle on Earth, the internal biological clock must be reset each day. Exposure to light is the single most powerful resetting agent (Czeisler, Weitzman, Moore-Ede, Zimmerman, & Knauer, 1980). If an individual is not exposed to light, the circadian rhythm will revert to its own internal time-keeping, which can create a transient misalignment between the solar day and internal timing (Flynn-Evans, Tabandeh, Skene, & Lockley, 2014). Light exposure at different times has different effects. For example, light in the biological evening (i.e., at habitual bedtime) can delay sleep timing, pushing sleep and wake times later, while light in the biological morning can shift sleep and wake times earlier. There are many factors which determine the effectiveness of light to reset the body clock, including the intensity, wavelength, pattern, and duration of the light exposure. When an individual is exposed to light during the biological night, such as is the case for shift workers and those experiencing jet lag, misalignment between the drive to sleep and the need to be awake, can occur.

With careful control of light exposure, it is possible for individuals to adjust to jet lag or stable shift schedules; however, it can take many days to adapt. Although such adaptation is possible, it is typically not practical in most shiftwork situations, where individuals revert to being awake during the day and asleep at night on days off (Smith & Eastman, 2012). Under typical circumstances, shiftwork or non-standard working hours may move the body clock by a few hours either side of the local norm (Flynn-Evans et al., 2018); however, the powerful effect of sunlight exposure prevents all but a few shiftworkers from adapting fully to non-standard hours (Hursh, Balkin, & Van Dongen, 2017).

A range of cognitive performance measures (including reaction time and short-term memory) have been shown to exhibit circadian rhythms, with reduced performance during the night hours, and improved performance during the normal hours of daylight and evening. Alertness and cognitive performance typically improve throughout the morning, as a function of the circadian drive to wake, even for a person who is sleep-deprived (Angus & Heslegrave, 1985).

The low point of the circadian rhythm typically occurs between 0200-0600h in individuals who sleep during the night and are awake during the day. The circadian low is characterized by lowered body temperature, diminished alertness, reduced cognitive performance, and an increased drive for sleep. A second, less pronounced period of increased fatigue and lowered performance typically occurs at around 1500h (Hursh, Balkin, Miller, & Eddy, 2004; Minors & Waterhouse, 1985). This period is sometimes referred to as the “post-lunch dip” however, it occurs even when no meal has been eaten. If an individual has partially adapted to a new circadian timing due to shiftwork or jetlag, this low may occur at other clock times that may be misaligned with the need to sleep or be alert.

There is individual variation in the preference for wake and sleep timing (known as chronotype). Morning types, commonly referred to as “larks” have a preference for waking early and going to bed early, whereas “night owls” evening types prefer to wake late and go to bed late (Horne & Ostberg, 1976). Beyond the preference for wake and sleep times, there is often an associated behavioral preference for when to perform mentally demanding tasks. Night owls tend to perform better later in the day when compared to their lark counterparts (Horne, Brass, & Petitt, 1980).

Daytime work hours are aligned with our circadian tendencies as work is set within the period characterized by a high circadian drive for alertness. However, shift work schedules covering 24-hour operations, especially night shifts, set work when the body is primed for sleep. This misalignment between the body clock and work timing leads to fatigue in two ways: (1) working at times when the circadian pressure for sleep is high (e.g. at night); and (2) by reducing the quality of preparatory and recovery sleep during the day when the circadian rhythm is promoting wakefulness. For example, studies of shiftworkers show a distinct peak in performance inefficiency (Folkard & Tucker, 2003) 2003), occupational injuries (Folkard, Lombardi, & Spencer, 2006) and subjective sleepiness (Folkard et al., 2005) between 0200-0600h. Further, shift workers report less sleep on night shifts than on day shifts or days off (Ferguson, Baker, Lamond, Kennaway, & Dawson, 2010).

3.1.6 Sleep Inertia

The term sleep inertia refers to the transient feeling of “grogginess”, disorientation, and associated performance impairment experienced upon waking (Jewett et al., 1999). Typically, sleep inertia dissipates in an asymptotic manner until approximately two hours after waking (Jewett et al., 1999), with most severe impairments occurring in the first 3-20 minutes after waking (Wertz, Ronda, Czeisler, & Wright, 2006). In the short-term, the performance impairment associated with sleep inertia can outweigh the recuperative effect of a nap (Ruggiero & Redeker, 2014). For example, it has been observed that performance after waking from a nap can be worse than performance after 21h of continuous wakefulness (Hilditch, Centofanti, Dorrian, & Banks, 2016) and modelling estimates that this may be the case following 48h of continuous wakefulness (Wickens, Laux, Hutchins, & Sebok, 2014).

The severity and duration of sleep inertia is dependent upon a number of factors including prior sleep history, sleep length, time of awakening, and sleep stage prior to waking (Tassi & Muzet, 2000). Sleep inertia tends to worsen with prior sleep loss (both acute and chronic), when awakening during the biological night, following long naps (>30min), and when woken from deep sleep (Scheer, Shea, Hilton, & Shea, 2008). The impact of sleep inertia also appears to be dependent on the type of task that is being completed during the sleep inertia episode with selective attention being particularly sensitive (Burke, Scheer, Ronda, Czeisler, & Wright, 2015). Although the factors described above can exacerbate sleep inertia severity and duration, it is important to note that sleep inertia can still occur following habitual sleep, brief naps, awakening from any sleep stage, and at any time of day (Achermann, Werth, Dijk, & Borbely, 1995; Hilditch, Dorrian, Centofanti, Van Dongen, & Banks, 2017).

Sleep inertia is of concern in workplaces where people must perform a critical function immediately after awakening, such as those who work on-call, or nap on-shift. There are several instances of real-world accidents in which sleep inertia was listed as a contributing factor (Transportation Safety Board of Canada, 2011; Government of India Ministry of Civil Aviation, 2010). Data from the Air Force suggest that the risk of a plane crash is higher in the first hour after waking (Ribak et al., 1983). In the maritime industry, an incident involving the heavy contact of two vessels was suspected to be partially due to sleep inertia. The chief officer of a platform supply vessel had only been awake for four minutes before arriving on the bridge to be briefed and make critical decisions that led to the incident (Marine Accident Investigation Branch, 2011).

3.1.7 Sleep Disorders

Chronic sleep loss may also arise from untreated sleep disorders, notably obstructive sleep apnea (OSA) and insomnia. OSA is a medical condition in which the upper airway is obstructed during periods of sleep, resulting in periods of reduced blood oxygen levels, and frequent arousals from sleep leading to sleep fragmentation (Young et al., 1993). Up to 18% of the population may be affected by OSA (Kang, Seo, Seo, Park, & Lee, 2014; Young et al., 2002).

OSA is a particular concern in the transport industry (Moreno et al., 2004). In the maritime sector, attention focused on this issue following a collision at Port Arthur, TX involving a vessel under the control of a maritime pilot who was suffering from untreated OSA (Strauch, 2015). Reid, Turek, and Zee (2016) found that personnel in the tug, towboat and barge industry had a higher level of risk factors for OSA compared to the general population. Based on this finding, it was recommended that the maritime industry follow the lead of other industries to improve screening and treatment for OSA and other sleep disorders.

3.1.8 Performance Effects of Fatigue

The effects of fatigue on cognitive performance are well-documented. The ability of an individual to self-assess their own fatigue, however, can be poor (Van Dongen et al., 2003). The detrimental effects of fatigue on human performance include slowed reaction time, impaired decision making, reduced attention, and increased incidence of human error (Van Dongen et al., 2003; Wickens, Hutchins, Laux, & Sebok, 2015).The International Maritime Organization lists the following possible effects on fatigue on job performance of maritime pilots (Table 1) (*Guidelines on Fatigue*, 2001).

Table 1 Signs And Symptoms of Fatigue-Related Performance Impairment

Inability to concentrate
*Unable to organize a series of activities
*Preoccupation with a single task
*Focuses on a trivial problem, neglecting more important ones
*Less vigilant than usual

Diminished decision-making ability
*Misjudges distance, speed, time, etc.
*Fails to appreciate the gravity of the situation
*Fails to anticipate danger
*Fails to observe and obey warning signs
*Overlooks items that should be included
*Chooses risky options
*Has difficulty with simple arithmetic, geometry, etc

Poor memory
*Fails to remember the sequence of task or task elements
*Has difficulty remembering events or procedures
*Forgets to complete a task or part of a task

Slow Response
*Responds slowly (if at all) to normal, abnormal or emergency situations

Mood change
*Quieter, less talkative than usual
*Unusually irritable

Attitude change
*Unaware of own poor performance
*Too willing to take risks
*Ignores normal checks and procedures
*Displays a "don't care" attitude
International Maritime Organization, 2001

3.1.9 Impact of Fatigue in the Maritime Industry

Fatigue is a long-recognized hazard that must be managed in the maritime industry (*Guidelines on Fatigue*, 2001; Sanquist, Raby, Maloney, & Carvalhais, 1996). This is in line with McCallum, Raby, and Rothblum (1996), who estimate that 16% of maritime accidents are related to fatigue. It is not necessary here to summarize the extensive literature on maritime fatigue, however, the following examples serve to illustrate the extent of the problem.

Folkard (1999) and Filor (1998) reported that groundings were more common at night than during the day. Another study showed a similar peak in ship collisions in the morning hours based on data drawn from 123 insurance claims (Folkard, 1997). Although the timing of these incidents may also reflect the relative availability of visual cues at night, the peaks are in line with data from other industries in which light is not a factor (e.g. in factories). An examination of 279 maritime accidents identified other major factors as contributing to fatigue in these incidents such as the number of consecutive days worked, days worked in the prior month, and hours on duty prior to the accident (McCallum et al., 1996). In estimating the risk of groundings, Akhtar and Utne (2014) analyzed 93 incidents and concluded that a fatigued operator on the ship's bridge increased the probability of groundings by 23%. This finding is similar to that reported by Starren et al. (2008) who found that between 11 - 25% of groundings and collisions are at least partly due to fatigue.

The broader sleep, circadian, and fatigue literature from in-laboratory studies together with the analysis of sleep, fatigue, performance, and safety indicators across multiple industries support the evidence of fatigue-related events in the maritime industry. These studies and events point to a direct need for greater study and management of fatigue in this industry.

Relationship Between Work Assignments, Scheduling and Staffing Levels

The relationship between work assignments, work scheduling and staffing levels are intertwined. The number and duration of tasks required to complete job assignments directly informs scheduling and staffing needs. Task assignments are typically the primary driver of staffing needs for a given organization, but task assignments are not the only consideration in determining staffing levels. Other factors, such as training, skills/licensing level of workforce, attrition, administrative responsibilities, and workload must all be considered when determining staffing needs. In addition, in industries where the timing of task execution is uncertain, particularly in transportation where weather and other factors can cause schedule delays, additional personnel may be needed to provide flexibility in service requirements. Similarly, in 24-hour operations, sleep loss and circadian misalignment interact with work hours, such that the risk of an operational error or accident after work increases due to fatigue. As a result, work hour restrictions may be necessary to manage fatigue, which also influence staffing levels.

The relationship between work hour rules and staffing needs is not always straight forward, particularly in industries that have unpredictable or safety-critical operations. In many safety-sensitive occupations, regulation determines the maximum work shift length and/or how many individuals are required to perform a given task. These parameters directly inform the number of individuals that are needed to complete task assignments. For example, in US passenger-carrier aviation operations, the Federal Aviation Administration (FAA) restricts the number of hours that a pilot is allowed to work based on the time-of-day and type of operation (i.e. long-haul or short-haul flight) (FAA regulation part 121, section 117). When weather or other factors lead to flight delays, reserve pilots are scheduled to be on call to take over flights from pilots who would otherwise exceed work hour limits. Similarly, in locations where pilot staffing is needed, but where few pilots live, airlines must arrange to position pilots to meet all service requirements (i.e. “deadheading). In addition, the FAA requires that additional pilots are scheduled to operate long-haul flights in order to provide rest opportunities during extended duty work shifts. These factors must be taken into account when determining how many pilots are required to meet service needs.

Given the nature of on-call schedules and board-on-arrival service in the maritime industry, more staffing may be needed to ensure that all ship traffic can be accepted as requested. According to an analysis of the San Francisco Bar Pilot operations, 23 pilots were estimated to be available to move ships on an average day, despite having 60 licenses (Hobbs et al., 2018).

4 Analysis of Dispatch Records

The goal of the study was to identify characteristics of the Puget Sound Pilot schedules that could increase the likelihood of fatigue and to develop a model to project the number of pilots needed to provide board-on-arrival service, while accounting for new work hour rules to reduce the likelihood of schedule-induced fatigue. There were two analysis activities undertaken to better understand the characteristics of the PSP work scheduling practices: (1) analyzing scheduling patterns for both work and off-watch period durations with time of day considerations; (2) using the dispatch data to generate a predictive model to estimate the number of pilots needed to provide board-on-arrival service. The scheduling factors considered were based on those identified by Rosekind (2005) and based on a request provided to PSP from the Board of Pilotage Commissioners (BoPC; memo dated August 10, 2018). Model-building required inclusion of additional factors such as volume of vessel traffic, types of assignments, retirements, travel, and administrative requirements (memo from BoPC to PSP on January 17, 2019).

Table 2. Scheduling factors considered in the present study.

Work Scheduling	*Fatigue Risks*	*Fatigue Management*
1. Length of work period	Long hours awake and time on task lead to increased risks	Limits hours awake and time on task
2. Length/timing of time off between work periods	Inadequate or poor sleep leading to acute sleep loss	Provide adequate sleep opportunity
3. Night work/time of day	Window of circadian low and early morning starts related to increased sleepiness and reduced performance	Limitations on time working when physiological alertness reduced
4. Consecutive days/nights working	Accumulated effects of operational demands and short-term chronic sleep loss	Limit cumulative effects of work and sleep loss
5. Work period start time variability	Disruption of circadian rhythms	Stability in daytime work timing allows circadian clock to stay in sync
6. Recovery periods between work cycles	Long-term chronic sleep restriction	Provide adequate nighttime recovery sleep opportunities
7. Number of callbacks	Long-term chronic sleep restriction	Provide sufficient opportunity for recovery and rest

Data and Processing

Scheduling data were obtained from PSP dispatch records. A total of 7,369 vessel moves completed by 54 unique pilots from October 2017 to September 2018 (the “trailing 12 months”) were included in the current analysis (including some who did not work the entire year due to retirements and new hires). A second analysis comprised 7,334 vessel moves for the calendar year from January 2018 to December 2018 was also performed (“calendar year analysis”). These separate analyses were completed, because PSP instituted a 10-hour minimum rest period beginning in October 2018. The trailing 12-month analysis allowed us to evaluate schedules before the implementation of these changes, while the calendar year analysis was completed to conform to the period of time typically assessed for the evaluation of pilot staffing needs.

In our statistical analyses, administrative work by the President of the Puget Sound Pilots was excluded. Dispatch information provided included “call time” and “check-in time” times for every work period (used to define start and end of work periods), “travel time” (i.e. allotment of time to travel to the assignment),“job time” (time of vessel boarding) and “completion time” (time of disembarking from the vessel) for every job within each work period, along with the *to* and *from* locations for each job. In addition, “reposition times” were included in the data (times when an individual must be moved from one duty station to another, similar to deadheading in aviation).

The dispatch data that was evaluated for this report was entered as an archival record and not for the purposes of surveillance and analysis. As a result, there were inconsistencies in some data entries that had to be reconciled prior to analysis. For example, when an individual had a series of training days, this was typically noted only on the first day in the series. Some types of vessel moves were modified from the dispatch dataset to account for common work scheduling practices as follows:

4.1.1 Multiple Harbor Shifts

Data were pre-processed to identify situations where a single pilot completed multiple short harbor moves within a work period. In these cases, the work period was defined as a multiple harbor shift (MHS) and was considered to last from the call time for the first vessel move to the check-in time of the last vessel move. In our analyses and plots multiple harbor shifts are listed as a single vessel move.

4.1.2 Cruise Ship Moves

During the timeframe reviewed, a single pilot would typically complete the inbound and outbound sailings for cruise operations. For these operations, each cruise ship move was considered as a separate assignment, with the time between the two moves considered a rest break.

4.1.3 Reposition Associated Moves

When vessel moves occurred within six hours of a reposition assignment, the reposition shift was combined with the vessel move in the data file and was considered a “reposition job.” The work period for these moves was considered to last from the call time for the first assignment to the check in time for the vessel move.

Statistical Analysis

Descriptive statistics were calculated from the ‘trailing 12 month’ dataset.

4.1.4 Linear Regression Modeling

We used a linear regression model to estimate the number of pilots required to handle all work assignments while reducing the frequency of callbacks and while accounting for work hour rules aimed at mitigating fatigue. Model building was conducted twice, once for the trailing 12 dataset and once for the calendar year dataset. Data were structured as frequency counts per day in order to allow for estimation of the impact of parameter changes on pilot staffing levels using intuitive inputs (i.e. inputs that could be modified by PSP to estimate the impact of a variety of hypothetical changes). Candidate predictors for the model were selected *a priori*, based on scheduling factors identified by Rosekind (2005) and a fatigue risk management review that was presented to the Board of Pilot Commissioners (Table 2). Predictors were screened to confirm a linear relationship to staffing levels. Predictors that were significant at the $p < 0.20$ level in the initial model were included in the final model. Beta coefficients and their associated confidence intervals were calculated for each predictor. These beta coefficients were then multiplied by hypothetical changes in work factors to estimate the number of pilots needed to complete work tasks given potential changes. For example, a beta coefficient was calculated to estimate the relative impact of callbacks on pilot staffing needs. This allows for input of different estimates for the number of callbacks per day and the associated impact on staffing levels by multiplying the beta coefficient by the estimated change in callbacks.

Given the current scheduling convention in maritime operations, approximately half of the pilots are scheduled to work most days, therefore the model estimates the number of pilots required on a single watch day. In order to determine total pilot staffing needs within this day-off-for-day-on framework, the final model estimate was doubled.

One pilot was added to the estimate in order to account for the Puget Sound President, who is not typically scheduled for ship movement activities. Finally, predictors that were not included in the final model, but that influence pilot staffing levels (e.g. accrued callbacks, hypothetical work hour changes, earned time off), were considered in separate analyses and added to the model estimate.

5 General Findings

Distribution and Timing of Assignments

Dispatch data included information on vessel movements, including number of callbacks to move ships on days off (callbacks), repositions of personnel (“repos”), jobs performed to upgrade one’s license (upgrades), training, meetings, compensation days taken for callback days worked (“comp days”), earned time off, and other activities (e.g. bereavement). The total number of activities in each of these categories is shown in Figure 2.

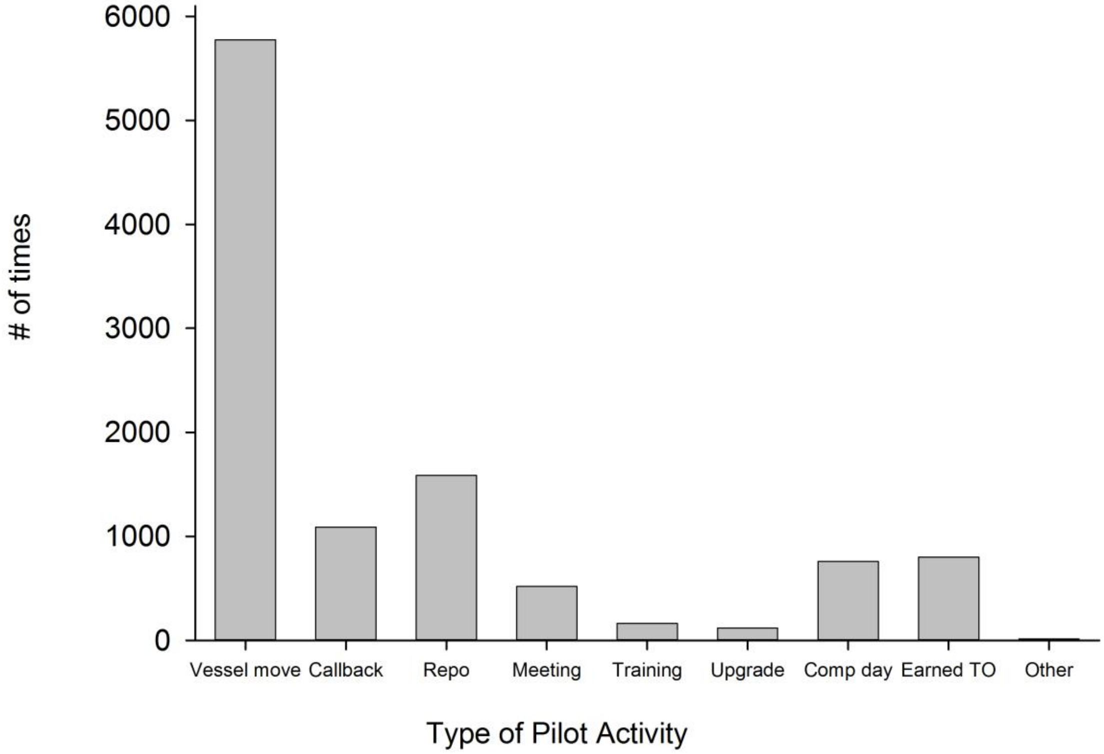


Figure 2. All pilot-related activities during the trailing 12-month period. Vessel move = vessel move completed by pilot while on watch, Callback = vessel move completed by pilot while off watch, Repo = repositions (includes those related to comp days), Meeting = pilot attending meeting, Training = pilot training, Upgrade = vessel move for upgrading pilot license, Comp Day = day off taken during watch as compensation for completing a callback job, Earned TO = earned time off, Other = bereavement, drug test and unfit for duty. Multiple harbor shifts are counted as a single vessel move assignment.

All assignments were inspected to identify patterns in the pilots’ schedules. It was apparent that some individual pilots became available for piloting assignments part way through the year or ceased working as a pilot before the year was over. Four pilots worked less than 20 days during the trailing 12 month period. The distribution of assignments for the remaining fifty pilots is shown in Figure 3, although some pilots retired or became unavailable for work partway through the year.

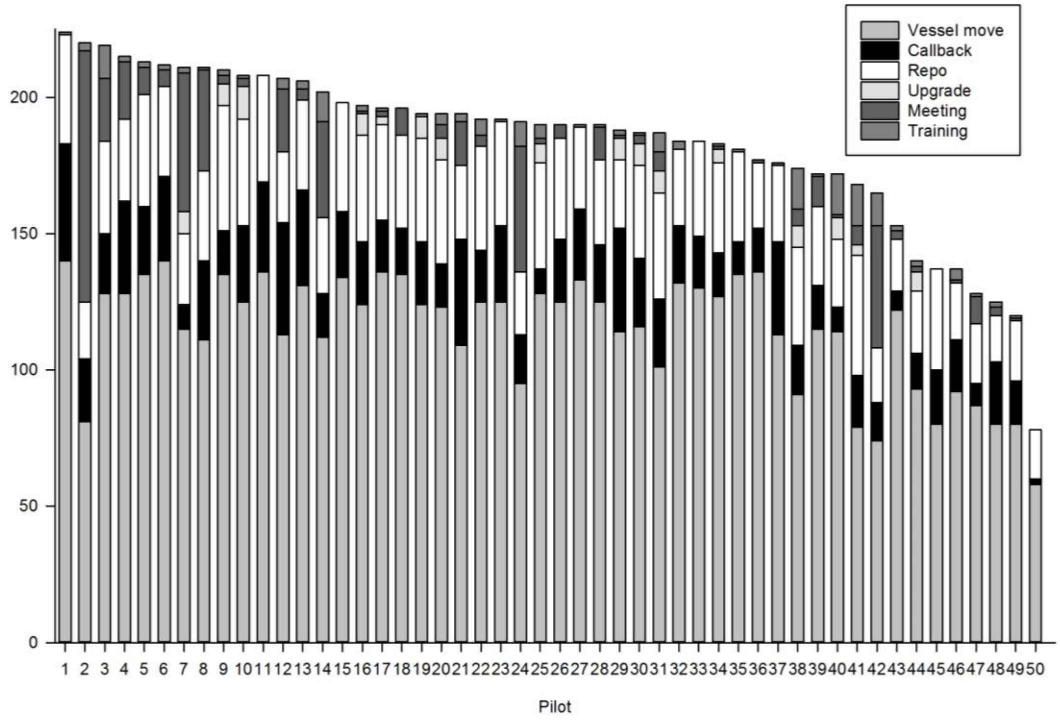


Figure 3. Assignments by pilot. Vessel move = vessel move completed by pilot while on watch, Callback = vessel move completed by pilot while of watch, Repo = repositions (includes those related to comp days), Meeting = pilot attending meeting, Training = pilot training, Upgrade = vessel move for upgrading pilot license. Multiple harbor shifts are counted as a single vessel move assignment.

Figures 4-5 show, the number of total work activities by month (Figure 4) and by day of the year (Figure 5). These figures highlight the sharp seasonal increase in vessel traffic that occurs during the cruise ship season from May until October. The daily variation in these patterns is apparent in Figure 5, where the average number of daily assignments is displayed as a dashed line. Overall, there were 25.3 assignments on an average day, with a minimum of 8 and a maximum of 47 (Figure 5).

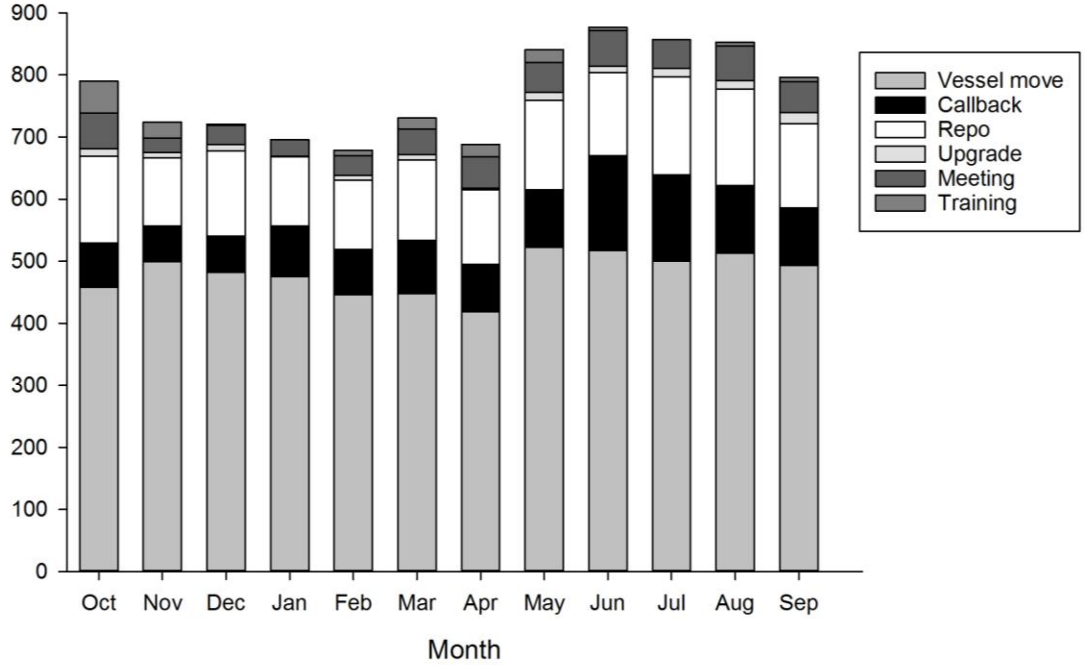
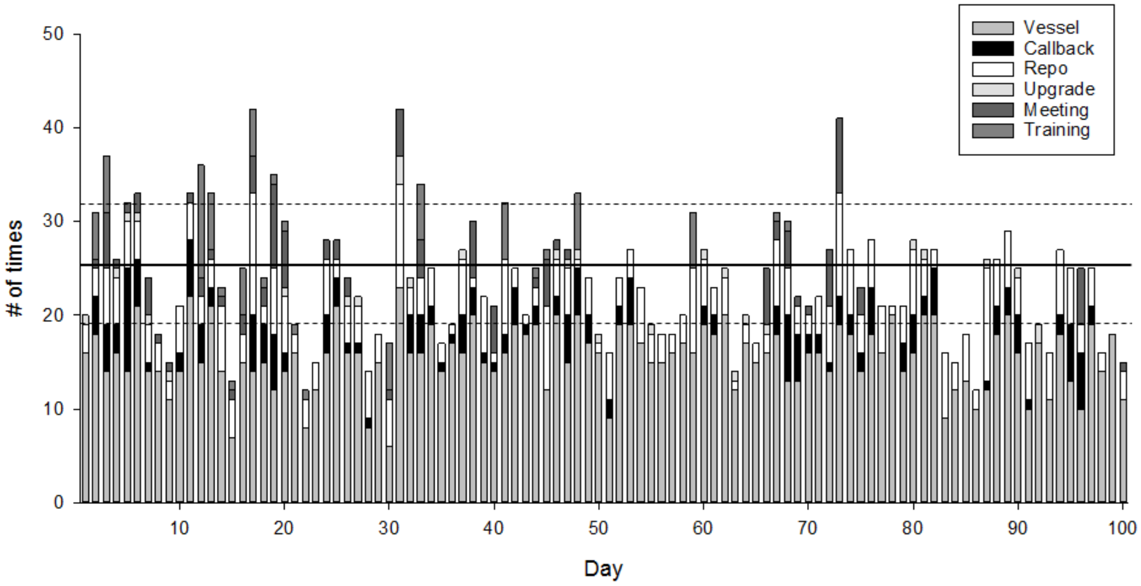
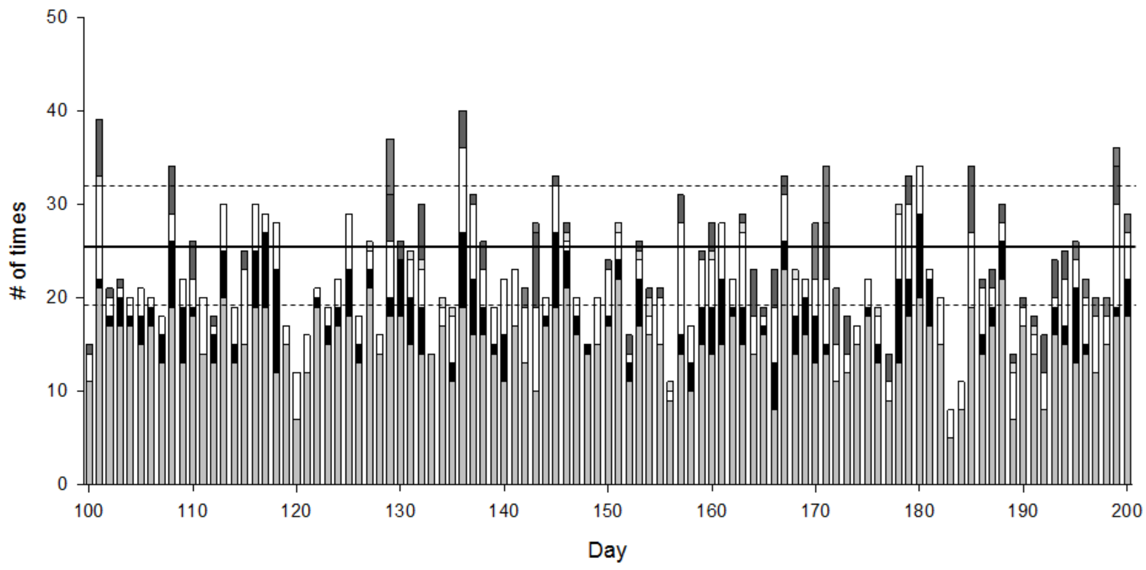
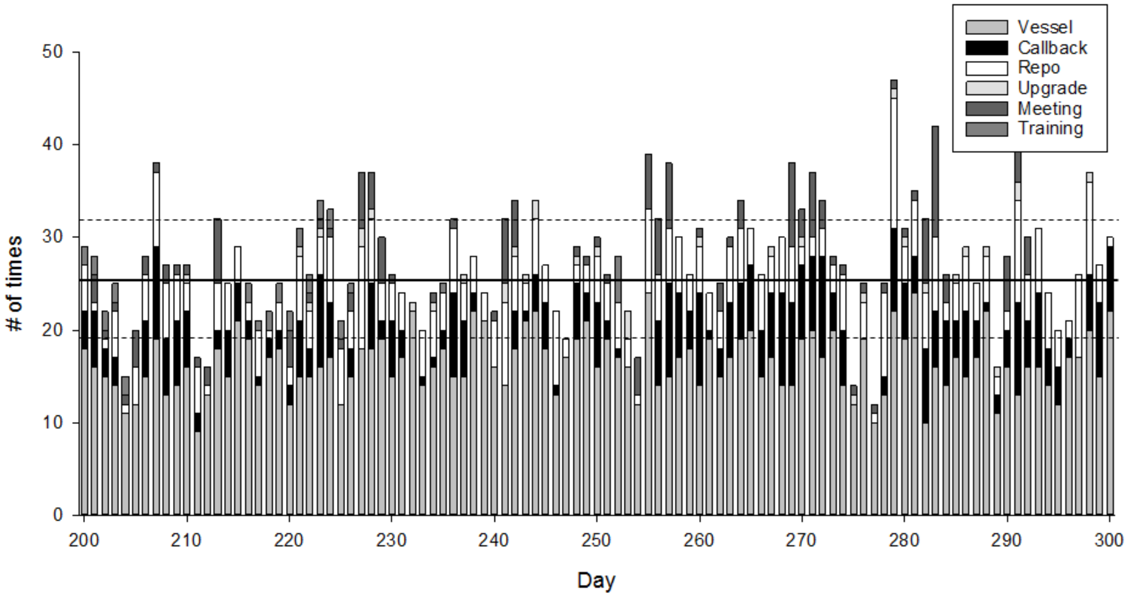


Figure 4. Assignments by month. Vessel move = vessel move completed by pilot while in rotation, Callback = vessel move completed by pilot while not in rotation, Repo = repositions (includes those related to comp days), Meeting = pilot attending meeting, Training = pilot training, Upgrade = vessel move for upgrading pilot license. Multiple harbor shifts are counted as a single vessel move assignment.




# of times
0
10
20
30
40
50
100
110
120
130
140
150
160
170
180
190
200
Day


Vessel
Callback
Repo
Upgrade
Meeting
Training
# of times
0
10
20
30
40
50
200
210
220
230
240
250
260
270
280
290
300
Day

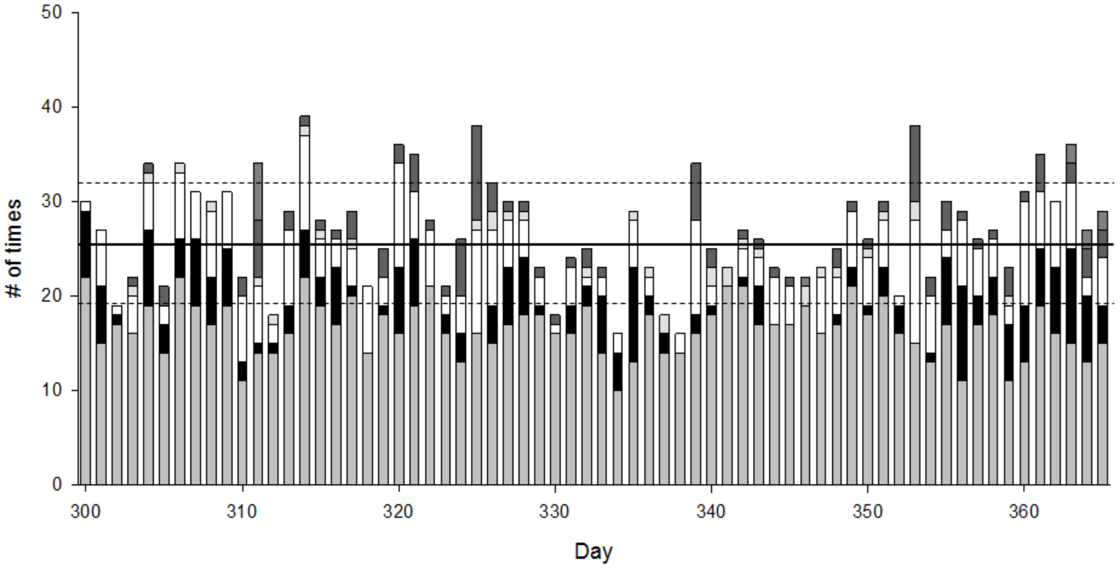


Figure 5. Assignments by day. Frequency of total daily pilot work-related activities across the 12-month period (top panel= days 1-100; following panels= days 101-200, days 201-300, days 301-365). The solid horizontal line represents the average daily total of 25.3 (+/- 6.5) activities with +1/-1 standard deviation presented above and below with dashed lines. Vessel = vessel move completed by pilot while in rotation, Callback = vessel move completed by pilot while not in rotation, Repo = repositions (includes those related to comp days), Meeting = pilot attending meeting, Training = pilot training, Upgrade = vessel move for upgrading pilot license. Multiple harbor shifts are counted as a single vessel move assignment.

There was minimal variation in the number of vessel moves by day of the week (Figure 6). Pilot repositioning and meetings peaked on Tuesdays, which is the change-over day between watch schedules.

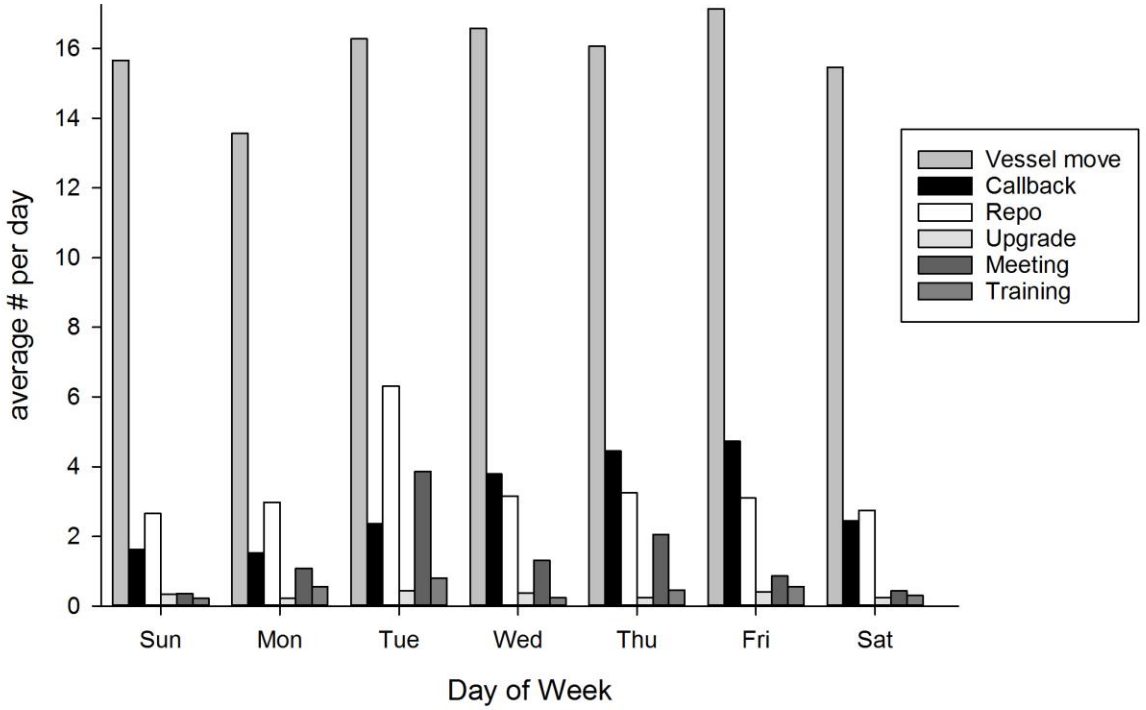
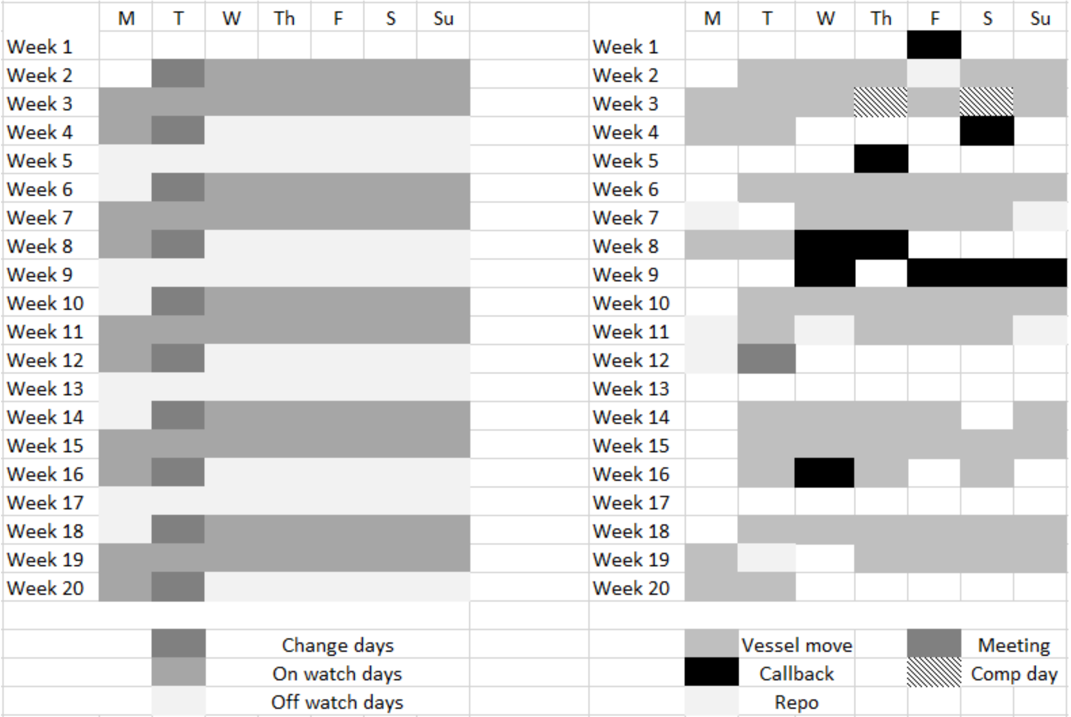


Figure 6. Assignment type averaged by day of the week. Vessel move = vessel move completed by pilot while in rotation, Callback = vessel move completed by pilot while not in rotation, Repo = repositions (includes those related to comp days), Meeting = pilot attending meeting, Training = pilot training, Upgrade = vessel move for upgrading pilot license. Multiple harbor shifts are counted as a single vessel move assignment.

Description of Work and Rest Periods

The timing of work and rest opportunities is an important factor in determining how fatiguing a work shift is likely to be. When individuals work during the biological night, circadian misalignment occurs, which causes individuals to feel sleepy during work periods and may inhibit one's ability to obtain adequate sleep during rest opportunities. In addition, pilots complete watch schedules of 15 days on, with 13 days off, which has the potential to cause chronic sleep deprivation, which can further degrade alertness and performance. As a result, it is critically important to understand how the timing of assignments is distributed throughout the day.

An example of the watch schedule for a single pilot is shown in Figure 7. The left panel shows the watch schedule, with each scheduled day of work shaded in gray. The right panel of Figure 7 shows the days the pilot actually worked during the same period of time. As illustrated in this figure, this pilot had numerous instances of work, including 10 callback shifts, during off-watch periods. As described previously, the timing of work assignments is an important factor in estimating fatigue risk. The timing of assignments over the 24-hour day for a single pilot is shown in Figure 8. This figure highlights the erratic timing of vessel assignments and also illustrates the number of times this pilot experienced a callback to help cover vessel moves on days off.



	M	T	W	Th	F	S	Su
Week 1							
Week 2		▓	▒	▒	▒	▒	▒
Week 3	▒	▒	▒	▒	▒	▒	▒
Week 4	▒	▓	░	░	░	░	░
Week 5	░	░	░	░	░	░	░
Week 6	░	▓	▒	▒	▒	▒	▒
Week 7	▒	▒	▒	▒	▒	▒	▒
Week 8	▒	▓	░	░	░	░	░
Week 9	░	░	░	░	░	░	░
Week 10	░	▓	▒	▒	▒	▒	▒
Week 11	▒	▒	▒	▒	▒	▒	▒
Week 12	▒	▓	░	░	░	░	░
Week 13	░	░	░	░	░	░	░
Week 14	░	▓	▒	▒	▒	▒	▒
Week 15	▒	▒	▒	▒	▒	▒	▒
Week 16	▒	▓	░	░	░	░	░
Week 17	░	░	░	░	░	░	░
Week 18	░	▓	▒	▒	▒	▒	▒
Week 19	▒	▒	▒	▒	▒	▒	▒
Week 20	▒	▓	░	░	░	░	░

▓ Change days
▒ On watch days
░ Off watch days

	M	T	W	Th	F	S	Su
Week 1					■		
Week 2		▒	▒	▒	░	▒	▒
Week 3	▒	▒	▒	▨	▒	▨	▒
Week 4	▒	▒				■	
Week 5				■			
Week 6		▒	▒	▒	▒	▒	▒
Week 7	░		▒	▒	▒	▒	░
Week 8	▒	▒	■	■			
Week 9			■		■	■	■
Week 10		▒	▒	▒	▒	▒	▒
Week 11	░	▒	░	▒	▒	▒	░
Week 12	░	▓					
Week 13							
Week 14		▒	▒	▒	▒		▒
Week 15		▒	▒	▒	▒	▒	▒
Week 16		▒	■	▒		▒	
Week 17							
Week 18		▒	▒	▒	▒	▒	▒
Week 19	▒	░		▒	▒	▒	▒
Week 20	▒	▒					

▒ Vessel move
■ Callback
░ Repo
▓ Meeting
▨ Comp day

Figure 7. A comparison of the watch rotation as scheduled (left panel) and as worked (right panel) over a 20-week period. On the left, the 15-on/13-off rotation schedule is presented with change days highlighted at the start and end of each on watch period. On the right, the actual schedule worked by the pilot with type of work period indicated.

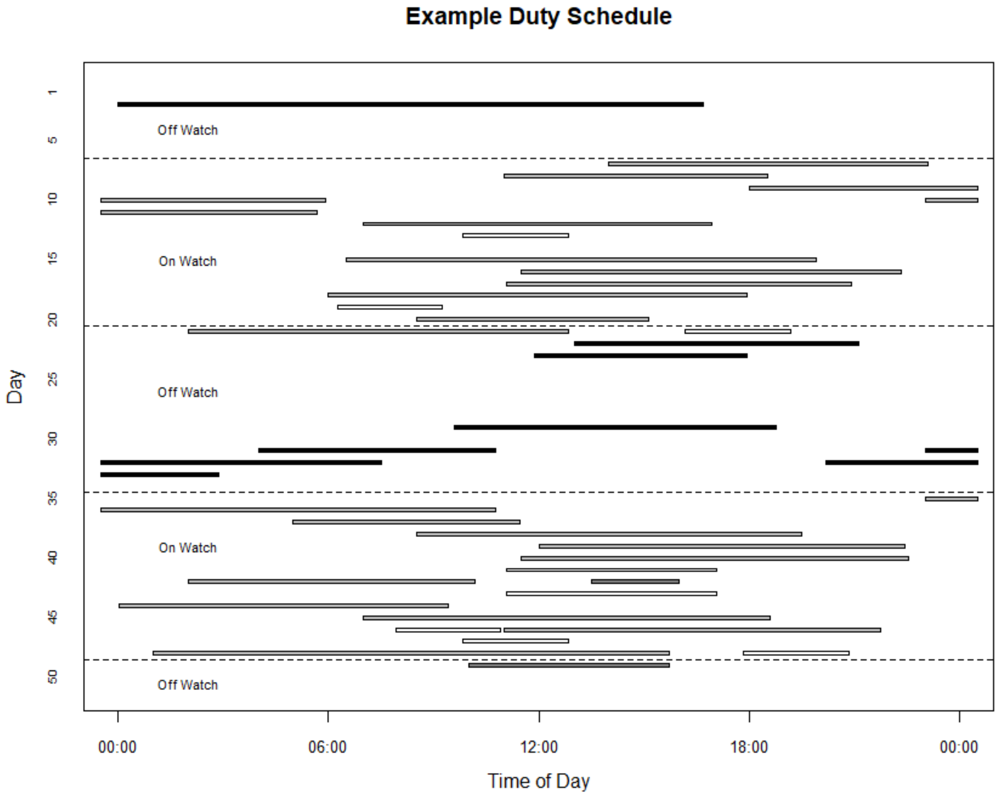


Figure 8. An example of a pilot’s work schedule over a 50-day period by time of day. On and off-watch periods are identified with change days (dashed line). All work-related activities are presented by day from start to end time. For night work periods that cross midnight (00:00), a bar is presented from the work start time to midnight, then is continued on the next day from midnight to the work period end time (an example is at the end of day 10, continuing on day 11). Work type: vessel movements on watch days (gray bars), callback assignments on days off (black bars), repositions (light gray bars), and meetings (dark gray bars).

As described previously, during each watch, pilots are assigned vessel moves as ship movements are communicated to the pilot dispatch. A pilot “call time” reflects the time that the pilot begins preparations for work prior to traveling to an assigned vessel move. The pilot “job time” reflects the time the pilot boards the vessel, and the pilot “check-in time” reflects the time when a vessel move has been completed and when a pilot is able to rest.

Figure 9 illustrates the call time, travel time, and end (check-in time) times for all vessel moves. Overall, the peak call times occurred between 1100 and 1159. The peak job time (i.e. the time the pilot boarded the vessel) occurred between 1400 and 1459. The most common hour for the end of work periods was 1700.

Given the large geography of the Puget Sound, which includes multiple ports and a pilot station at Port Angeles, coupled with different types of vessel traffic (e.g. container vessels, cruise ships, tankers), we examined the call time, job time, and check-in time by location of assignment for origin points that included a large number of vessel moves. Figure 10 illustrates the call time, job time and check-in times for single inbound vessel moves from Port Angeles Pilot Station. For these types of moves, we found that peak call times occurred between 0900-1059 and between midnight and 0159. The peak job time (i.e. the time the pilot boarded the vessel) occurred between midnight and 0100, with a second peak 0900. The most common hour for the end of work periods was 0700, with secondary peaks between 1700 and 1959.

Outbound vessel moves originating in Tacoma followed a different pattern, with peak call times occurring between 1200 and 1359 (Figure 11). The peak job time (i.e. the time the pilot boarded the vessel) occurred between 1700 and 1859. The most common hour for the end of work periods originating in Tacoma was 2300. Outbound essel moves originating from Seattle, which involve the majority of outbound cruise ship operations, had a peak call time of 1100 (Figure 12). The job time peak occurred between 1400 and 1500. The peak check-in time in Seattle was 1700.

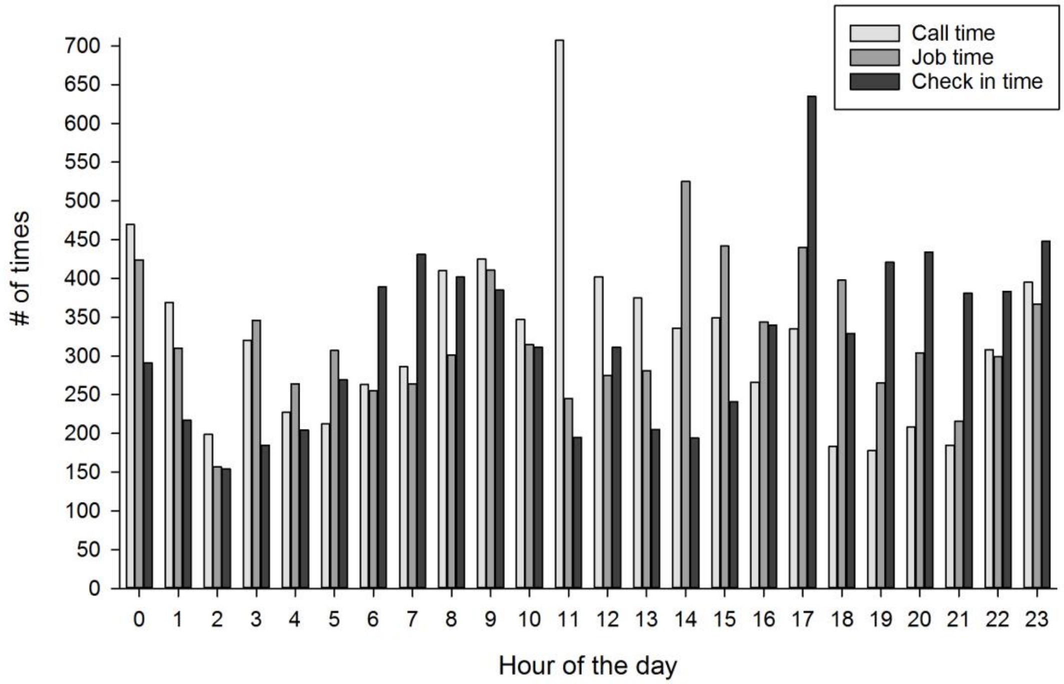


Figure 9. Distribution of vessel move-related activities by hour of the day for all vessel moves. The call time is the time that a work period begins, the job time is the time that the pilot boards the vessel, and the check-in time is the time that the work period ends following a vessel move.

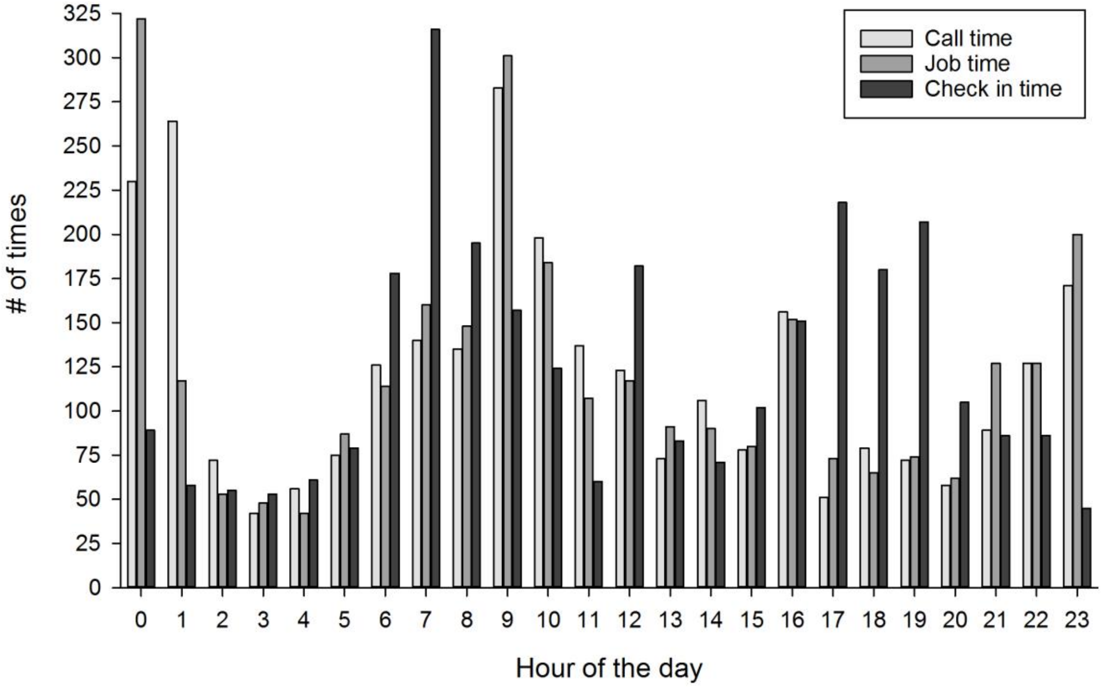


Figure 10. Distribution of vessel move-related activities by hour of the day for single vessel moves (i.e. excluding multiple harbor ship moves) for inbound traffic (from Port Angeles Pilot Station). The call time is the time that a work period begins, the job time is the time that the pilot boards the vessel, and the check-in time is the time that the work period ends following a vessel move.

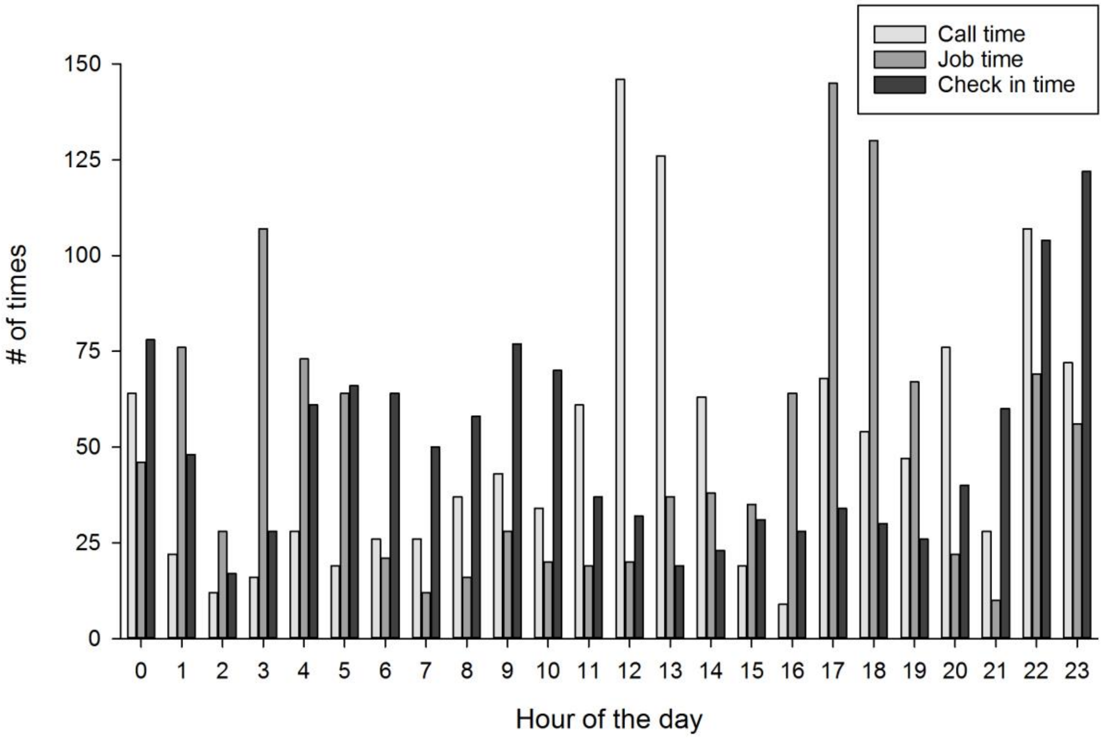


Figure 11. Distribution of vessel move-related activities by hour of the day for single vessel moves (i.e. excluding multiple harbor ship moves) from Tacoma. The call time is the time that a work period begins, the job time is the time that the pilot boards the vessel, and the check-in time is the time that the work period ends following a vessel move.

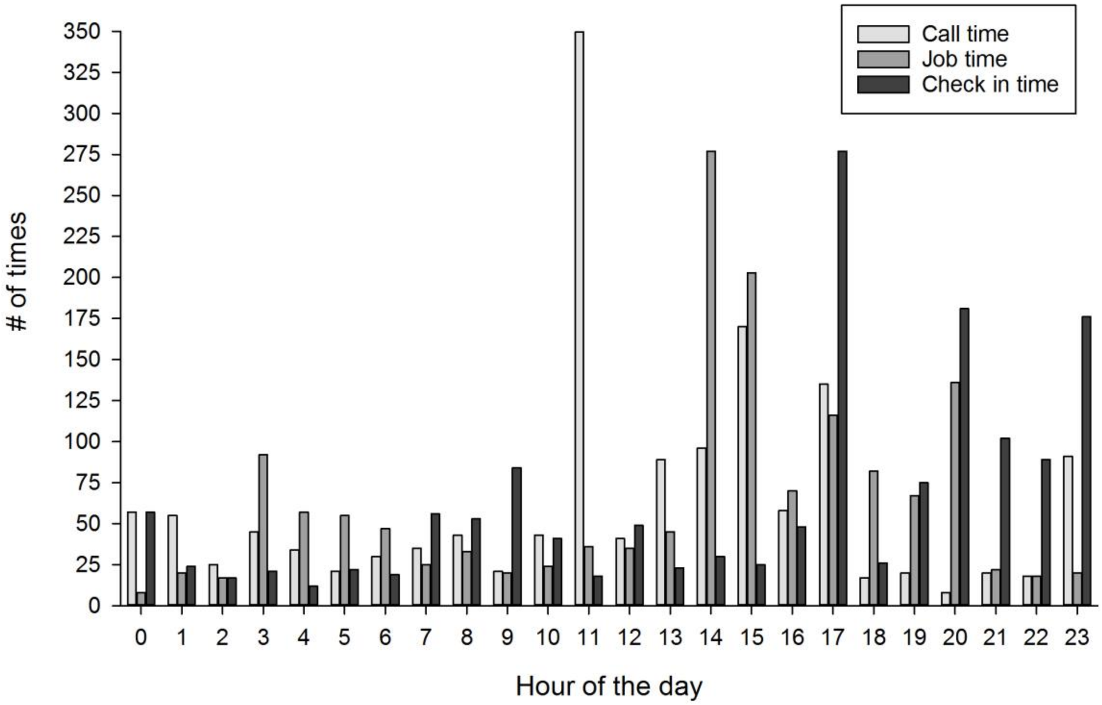


Figure 12. Distribution of vessel move-related activities by hour of the day for single vessel moves (i.e. excluding multiple harbor ship moves) from Seattle. The call time is the time that a work period begins, the job time is the time that the pilot boards the vessel, and the check-in time is the time that the work period ends following a vessel move.

The duration of a work shift also contributes to fatigue while at work. Pilots worked an average of 99.1 hours per on-watch period and 9.4 hours per work period, with a maximum recorded on-watch period of 157.8 hours. Pilots worked more than 12 hours in a work period 19% of the time and they worked 120 hours or more during an on-watch period about 24% of the time. Figure 13 illustrates the average work period duration based on start time (hour of day). Work period duration was found to be shortest when starting between 1500 and 1659. Work periods starting during the circadian low point, between 0100 and 0500, had the longest average work duration of approximately 10.5 hours. Work periods starting between 0600 and 1000 had an average work duration of approximately 8.8 hours. Pilots typically had 10.5 total piloting job assignments during an on-watch period with a maximum of 16. Pilots worked more than 12 times during an on-watch period about 27% of the time.

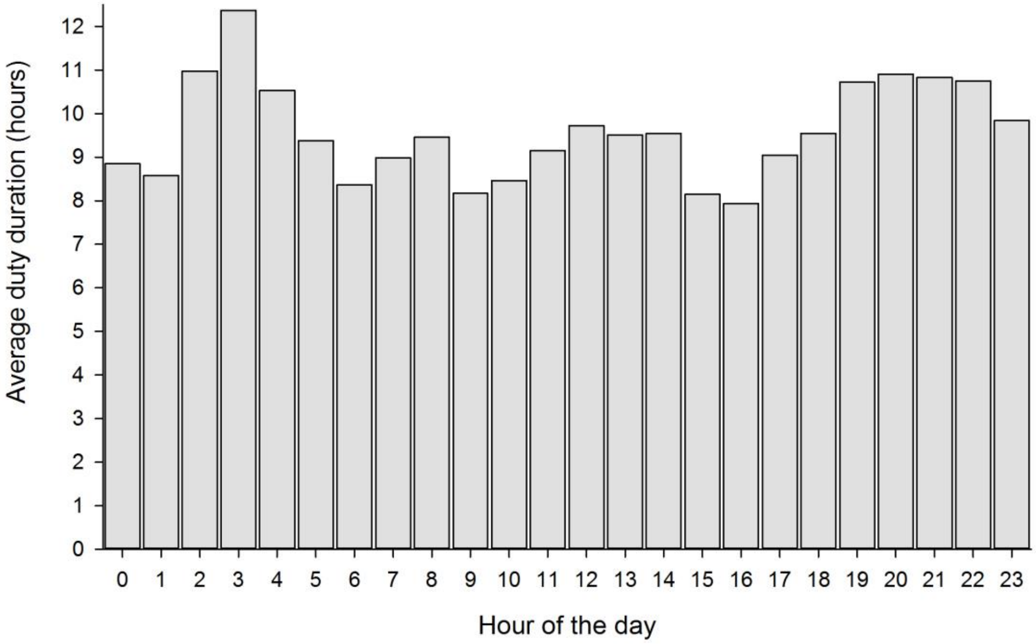


Figure 13. Work period duration by start hour.

Work Characteristics of Multiple Harbor Shifts and Cruise Operations

Multiple harbor shifts, cruise operations and repositions that allowed for immediate assignments were the primary reasons for extended-duty work shifts. Multiple harbor shift work periods (n= 257) averaged 13.0 h in duration and included an average of 2.3 vessel moves per assignment. The distribution of multiple harbor shift work hours is shown in Figure 14.

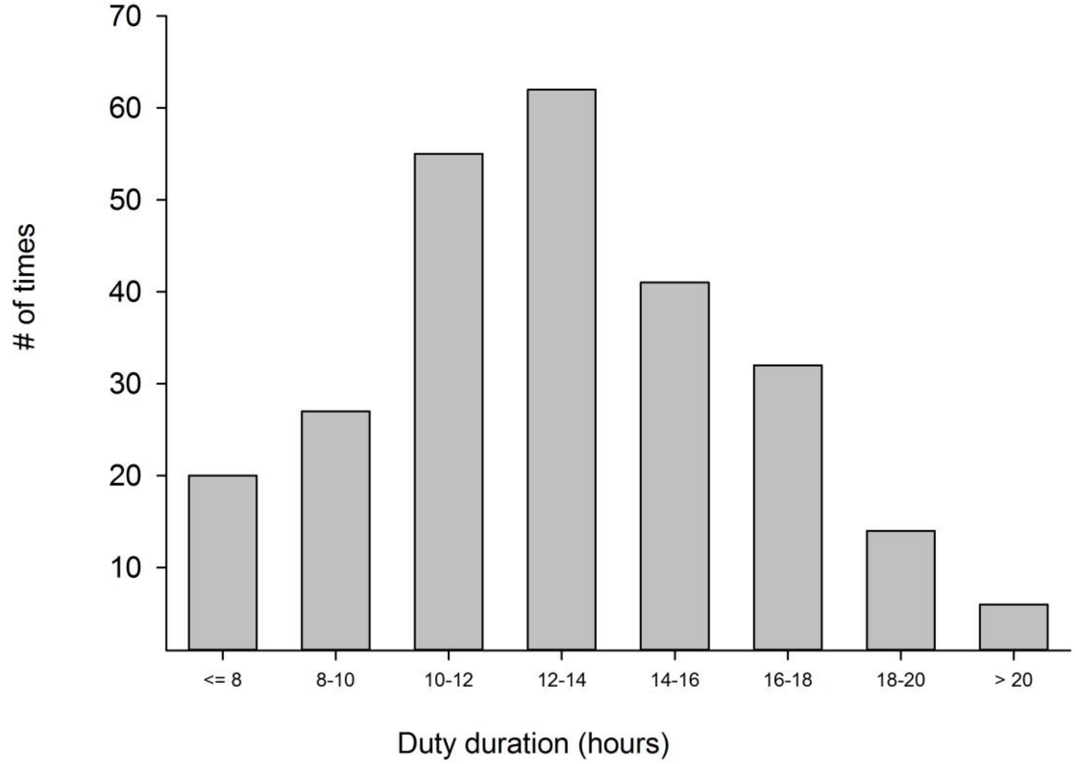


Figure 14. Distribution of multiple harbor shift work periods.

Inbound and outbound vessel moves to and from Seattle for cruise operations were typically handled by the same pilot. The majority of these vessel moves involved a night assignment for the inbound move, followed by a layover where a brief rest period might be possible, and a daytime assignment for the outbound move. Thirty-nine different pilots with the necessary license 5 served cruise ships during the 12-month period, with a maximum of seven by several pilots. An example of cruise operations for a single pilot is shown in Figure 15. Descriptive statistics summarizing cruise operations are shown in Table 3.

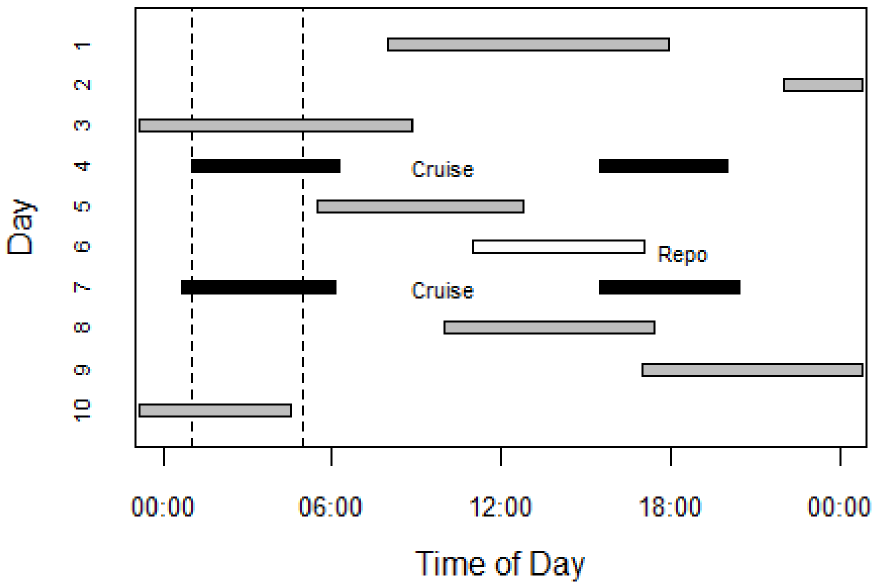


Figure 15. An example of a work schedule including 2 cruise operations by a single pilot during a 4-day period. Rotation assignments for the 2 days preceding the first cruise and for the 3 days following the second cruise are also shown. The 0100-0459 night period is highlighted with dashed lines. Cruise operations are shown in black, other assignments are shown in gray, and repositions are shown in white. For the inbound cruise operation, call time to job completion time is presented, while for the outbound, job time to check-in time is presented.

Table 3. Timing of cruise operations.

	n	Call/Job-time (h, SD)	Check-in time (h, SD)	Duration (h, SD)	Layover Period (h, SD)
Cruise Inbound	133	00:43 (0:26)	6:11 (0:22)	5.5 (0.4)	13.3 (8.6)
Cruise Outbound	133	15:13 (0:54)	20:34 (1:08)	4.8 (0.7)	8.9 (1.8)

h = hour, SD = standard deviation.

Description of Rest Periods

During on-watch periods, pilots worked 7 or more days in a row without a break of at least 24 hours about 8% of the time. The maximum number of consecutive days worked without such a break was 16 days.

We examined the number of hours off duty between consecutive work periods during on-watch periods (Figure 16). Pilots had an average of 17.1 hours off duty between consecutive work periods (based on check-in time to call time). Pilots received less than 10 hours off 16% of the time and less than 12 hours off duty 30% of the time.

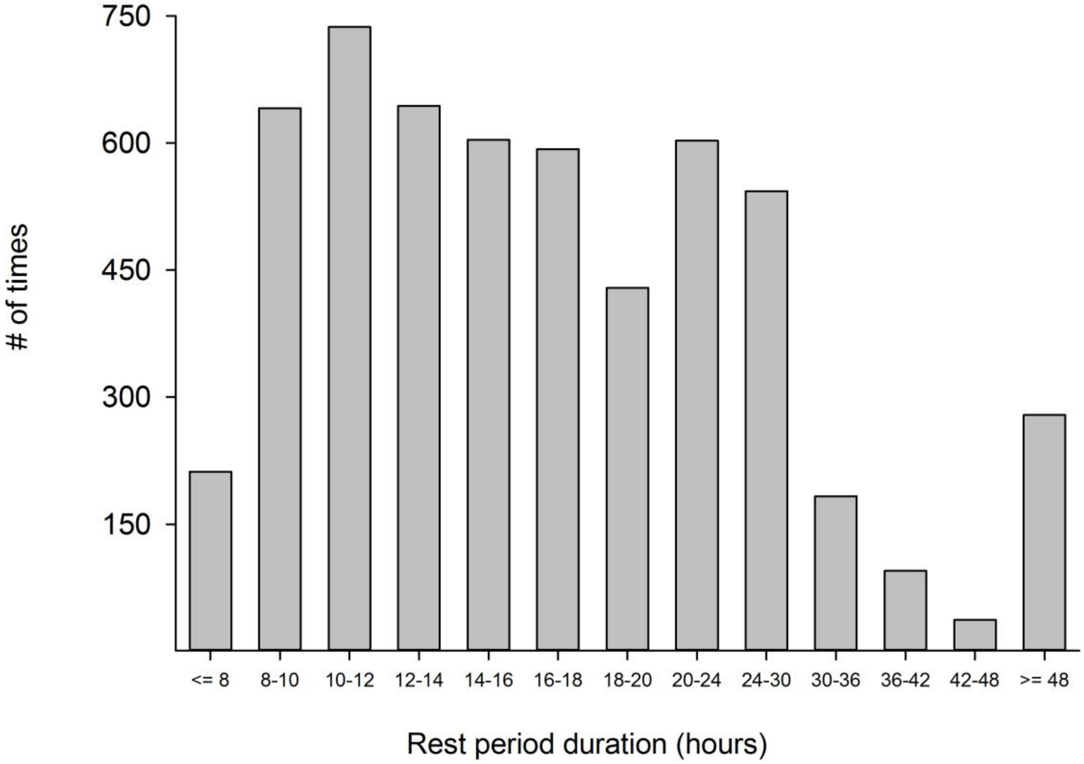


Figure 16. Distribution of hours off duty between consecutive on-watch work periods. Periods when one or more compensation days were taken were excluded from this analysis.

Retirement and Licensing

The Puget Sound Pilot workforce is skewed towards retirement, with seven pilots over 65 currently working, and an additional nine over 60 (Figure 17). More than 50% of the pilot workforce will be eligible for retirement within 10 years. This is reflected in the current license level of pilots, with the majority of ship moves being completed by pilots with license level five. The majority of vessels required Level 1 and Level 5 license holders, while pilots with Level 5 licenses completed the majority of vessel moves (Figure 18).

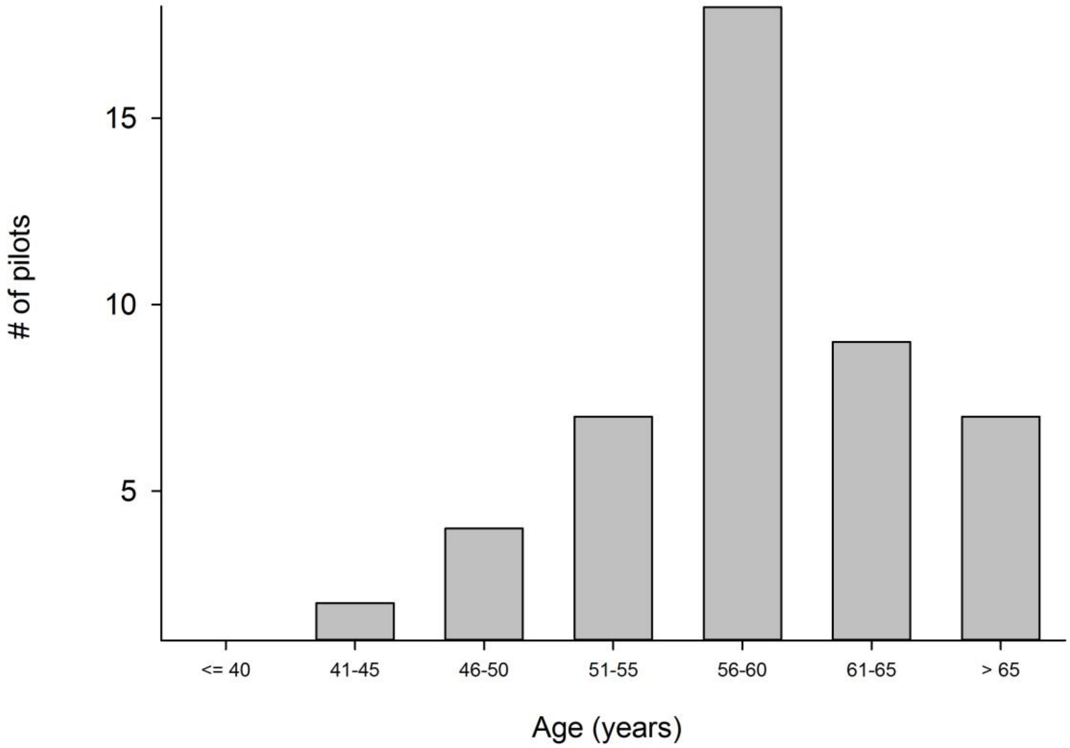


Figure 17. Distribution of Puget Sound Pilot age.

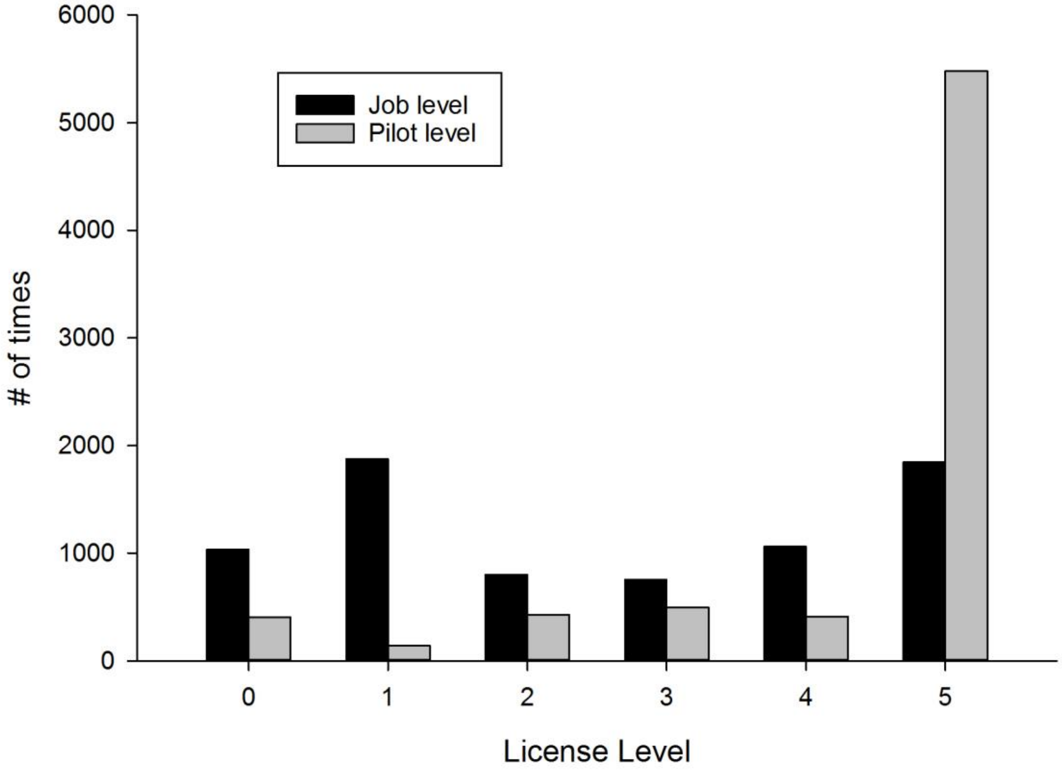


Figure 18. Distribution of license level required to pilot a vessel and the license level of pilots completing vessel moves.

Earned Time Off and Compensation Time

Pilots are granted 1.4 days of earned time off per watch worked (i.e. 7 days off after five watch periods, 5.5%). If a pilot has unused vacation days, then these days do not accrue and cannot be carried over year to year. This earned time off rate means that any day of the year the number of pilots available for watch would be reduced by 2-3 due to those using earned time off. In order to ensure enough pilots are on watch to provide board-on-arrival service, while covering earned time off, the total number of pilots must be increased by a factor of 0.055.

As described previously, pilots are provided with a day off as compensation for each day worked during days when they would otherwise be off watch. The current staffing levels appear to prevent pilots from taking compensation days, which means that they accrue at a rate that is faster than they are used. As a result, many pilots have a bank of unused compensation days. There were 1,210 compensation days earned by pilots for days worked during scheduled off-watch periods (calendar year dataset). During the same timeframe, only 785 compensation days were taken. The carry-forward of compensation days from prior years, combined with the positive accruals from 2018 led to a ‘bank’ of 3,143 compensation days, which is equivalent to 16 years of pilot work. Compensation days do not expire, therefore many pilots use all of their compensation days in the time leading up to retirement. If no changes are made to staffing, then this bank will continue to accrue. If four additional pilots had started work on January 1, 2019 and if callbacks were limited to an average of one every other day, then the "banked" compensation would still take more than 2 years to stabilize (Figure 20).

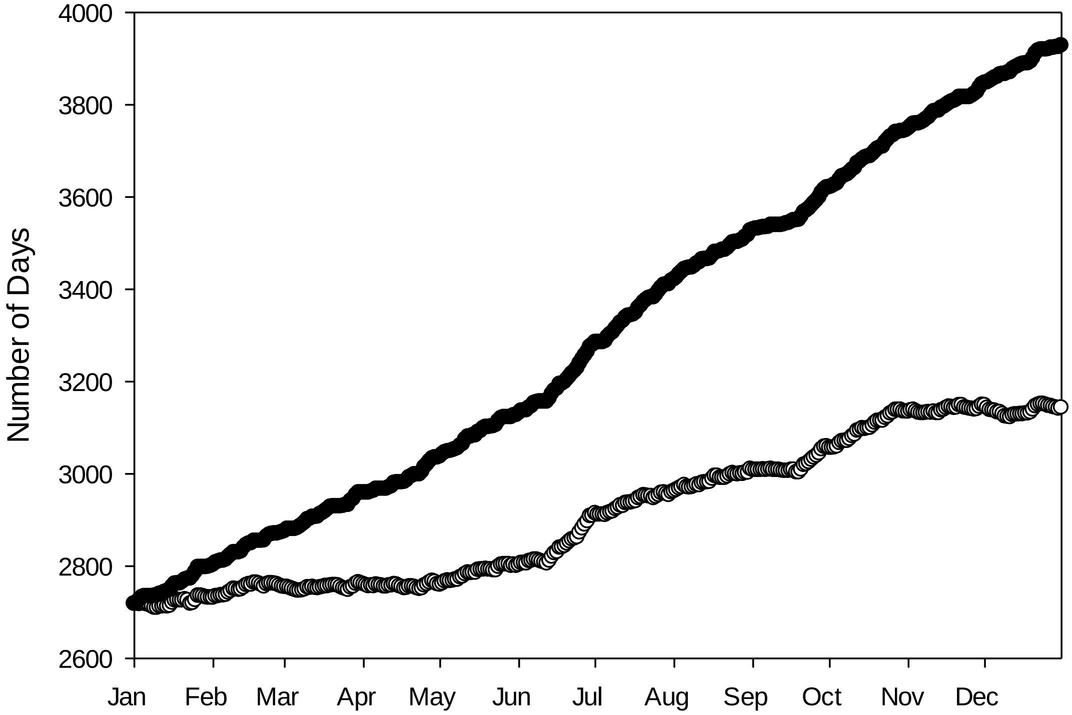


Figure 19. Compensation day accrual (black line) and compensation accrual minus compensation days taken (gray line) by day for the calendar year analysis.

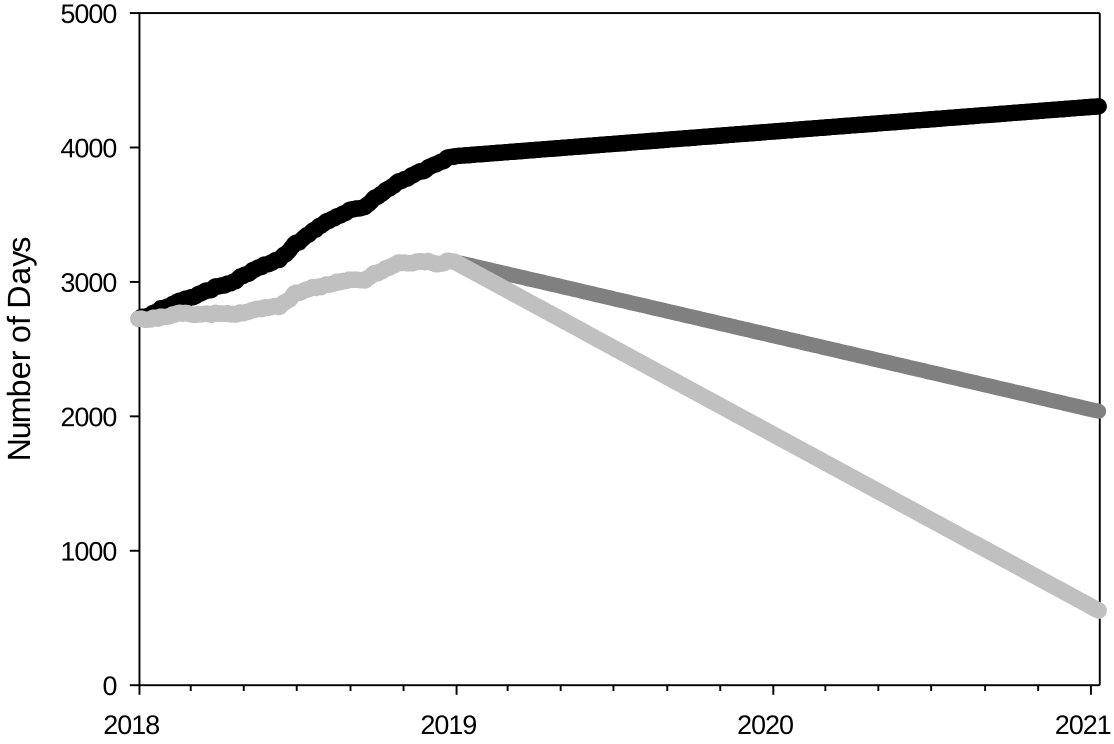


Figure 20. Hypothetical changes in compensation time accrual and payback based on different staffing models. Hypothetical changes would have started January 1, 2019. Black line projects compensation accrual if callbacks were limited to one every other day with no compensation days taken. Dark gray line projects compensation accrual if callbacks were limited to one every other day and if two compensation days were taken each day (e.g. linear regression model estimates with no additional pilots hired). Light gray line projects compensation accrual if callbacks were limited to one every other day and if two additional compensation days were taken per day (four additional pilots).

Linear Regression Modeling

Table 4 shows significant predictors in the model, their associated beta coefficients, and the average value for each predictor for the 'trailing 12-month' dataset. By multiplying the average values for each predictor by its corresponding beta coefficient, the total number of pilots that worked to complete all assignments is calculated. For Table 4, this calculation equals the equivalent number of pilots who worked during the year. That is, although there were 54 pilots included in the trailing 12-month dataset, due to retirements and injuries, there were only the equivalent of 47 pilots available for work throughout the year (i.e. 23.41 *2). This estimate can be considered the number of pilots needed to cover the average number of assignments for the year assessed. The confidence intervals reflect the potential range of pilots needed to complete all assignments on a given day. Given the large variability in ship traffic day-to-day, the confidence intervals can be considered as the number of pilots needed to cover all ship traffic on an average low day (lower confidence estimate) and the number of pilots needed to cover all ship traffic on an average high day (upper confidence estimate) without violating work hour rules and while accounting for other changes as factored into the model (e.g. reducing callbacks).

The average-by-day values for each predictor can be changed to determine how a given variable would affect staffing requirements. For example, Table 5 illustrates how eliminating callbacks alone would modify staffing requirements.

Based on best practices for fatigue risk management and expert recommendations provided to the Board of Pilot Commissioners, our final model is based on the introduction of work hour restrictions to minimize fatigue. Table 6 shows our final model using the trailing-12 dataset and Table 7 shows our final model using the calendar year dataset. Some of the variables that were significant in the models are different between the two datasets. This is likely due to the changes in work scheduling procedures that occurred during 2018. In addition, there were some factors that were not significant predictors in the model, but that are known important considerations in determining staffing needs. These variables were considered and added to the model in the next section.

Parameter	Beta Coefficient	p value	95% CI lower	95% CI upper	Average	Prediction estimate	95% CI estimate lower	95% CI estimate upper
Intercept	17.48	<.0001	15.10	19.85	--	17.48	15.10	19.85
Vessel movement	0.18	0.01	0.05	0.31	15.82	2.84	0.77	4.91
Callbacks	-0.46	<.0001	-0.60	-0.32	2.98	-1.37	-1.80	-0.94
Repositions	0.68	<.0001	0.52	0.84	4.35	2.95	2.25	3.65
Training	0.52	0.00	0.22	0.82	0.45	0.23	0.10	0.37
Meetings	0.84	<.0001	0.64	1.04	1.42	1.19	0.91	1.48
Comp days	0.44	0.00	0.18	0.70	2.08	0.92	0.38	1.46
> 60 h work/week	-0.12	0.02	-0.23	-0.02	5.21	-0.65	-1.18	-0.11
< 60 h rest 30 days	-1.52	0.11	-3.37	0.34	0.04	-0.07	-0.15	0.01
MHS > 13 h	-0.22	0.47	-0.82	0.38	0.53	-0.12	-0.43	0.20
Total						**23.41**	**15.95**	**30.88**

Table 4. Linear regression model showing the calculated beta coefficients and their associated confidence intervals and p-values for the predictors included in the model for the trailing-12 dataset. The average column shows the averages for each variable, derived from the dataset. The prediction estimate and associated confidence intervals are multiplied by the model predictions, then added together to reflect the number of pilots who completed assignments during the year in question. Comp days = compensation days, h = hour, MHS = multiple harbor shifts, CI = confidence interval.

Parameter	Beta Coefficient	p value	95% CI lower	95% CI upper	Expected per day	Prediction estimate	95% CI estimate lower	95% CI estimate upper
Intercept	17.48	<.0001	15.10	19.85	--	17.48	15.10	19.85
Vessel movement	0.18	0.01	0.05	0.31	18.80	3.37	0.91	5.84
Callbacks	-0.46	<.0001	-0.60	-0.32	0.00	0.00	0.00	0.00
Repositions	0.68	<.0001	0.52	0.84	4.35	2.95	2.25	3.65
Training	0.52	0.00	0.22	0.82	0.45	0.23	0.10	0.37
Meetings	0.84	<.0001	0.64	1.04	1.42	1.19	0.91	1.48
Comp days	0.44	0.00	0.18	0.70	2.08	0.92	0.38	1.46
> 60 h work/week	-0.12	0.02	-0.23	-0.02	5.21	-0.65	-1.18	-0.11
< 60 h rest 30 days	-1.52	0.11	-3.37	0.34	0.04	-0.07	-0.15	0.01
MHS > 13 h	-0.22	0.47	-0.82	0.38	0.53	-0.12	-0.43	0.20
Total						**25.32**	**17.89**	**32.75**

Table 5. Example of a predictive linear regression model showing the calculated beta coefficients and their associated confidence intervals and p-values for the predictors included in the model for the trailing-12 dataset. The ‘expected per day’ column shows the anticipated values for each predictor by day. In this example, callbacks were set at 0 in order to reflect pilot staffing needs in a hypothetical scenario where no callbacks occur. Given that callbacks are equivalent to vessel movements in the model, the vessel movement value is increased to reflect the expected average traffic by day. The prediction estimate and associated confidence intervals are multiplied by the model predictions, then added together to generate a prediction and range for the number of pilots needed to complete future work assignments given the inputs. Comp days = compensation days, h = hour, MHS = multiple harbor shifts, CI = confidence interval.

Parameter	Beta Coefficient	p value	95% CI lower	95% CI upper	Expected per day	Prediction estimate	95% CI estimate lower	95% CI estimate upper
Intercept	17.48	<.0001	15.10	19.85	--	17.48	15.10	19.85
Vessel movement	0.18	0.01	0.05	0.31	18.30	3.28	0.89	5.68
Callbacks	-0.46	<.0001	-0.60	-0.32	0.50	-0.23	-0.30	-0.16
Repositions	0.68	<.0001	0.52	0.84	4.35	2.95	2.25	3.65
Training	0.52	0.00	0.22	0.82	0.45	0.23	0.10	0.37
Meetings	0.84	<.0001	0.64	1.04	1.42	1.19	0.91	1.48
Comp days	0.44	0.00	0.18	0.70	4.00	1.76	0.72	2.80
> 60 h work/week	-0.12	0.02	-0.23	-0.02	0.00	0.00	0.00	0.00
< 60 h rest 30 days	-1.52	0.11	-3.37	0.34	0.00	0.00	0.00	0.00
MHS > 13 h	-0.22	0.47	-0.82	0.38	0.00	0.00	0.00	0.00
Total						**26.67**	**19.67**	**33.67**

Table 6. Linear regression model showing the calculated beta coefficients and their associated confidence intervals and p-values for the predictors included in the model for the trailing-12 dataset. The ‘expected per day’ column shows the anticipated values for each predictor by day. In this model, the expected per day values were set to reflect changes to pilot operations aimed at minimizing fatigue. Note: given that callbacks are

equivalent to vessel movements in the model, the vessel movement value is increased by the relative decrease in callbacks to reflect the expected average traffic by day. The prediction estimate and associated confidence intervals are multiplied by the model predictions, then added together to generate a prediction and range for the number of pilots needed to complete future work assignments given the inputs. Comp days = compensation days, h = hour, MHS = multiple harbor shifts, CI = confidence interval.

Parameter	Beta Coefficient	p value	95% CI lower	95% CI upper	Expected per day	Prediction estimate	95% CI estimate lower	95% CI estimate upper
Intercept	17.48	<.0001	15.10	19.85	--	17.48	15.10	19.85
Vessel movement	0.18	0.01	0.05	0.31	17.65	3.17	0.86	5.48
Callbacks	-0.46	<.0001	-0.60	-0.32	1.00	-0.46	-0.60	-0.32
Repositions	0.68	<.0001	0.52	0.84	4.22	2.87	2.19	3.55
Training	0.52	0.00	0.22	0.82	0.42	0.22	0.09	0.35
Meetings	0.84	<.0001	0.64	1.04	1.54	1.29	0.98	1.60
Comp days	0.44	0.00	0.18	0.70	4.00	1.76	0.72	2.80
> 60 h work/week	-0.12	0.02	-0.23	-0.02	0.00	0.00	0.00	0.00
> 12 h work/day	-0.22	0.47	-0.82	0.38	0.00	0.00	0.00	0.00
MHS > 13 h	-1.52	0.11	-3.37	0.34	0.00	0.00	0.00	0.00
Total						**26.33**	**19.35**	**33.31**

Table 7. Final Model. Linear regression model for the calendar year dataset. Presented are the calculated beta coefficients and their associated confidence intervals and p-values for the predictors included in the model. The ‘expected per day’ column shows the anticipated values for each predictor by day. In this model, the expected per day values were set to reflect changes to pilot operations aimed at minimizing fatigue while also reducing the bank of compensation day accruals (increasing by 2 comp days taken per day) and reducing the rate of callbacks to one per day. Note: given that callbacks are equivalent to vessel movements in the model, the vessel movement value is increased by the relative decrease in callbacks to reflect the expected average traffic by day. The prediction estimate and associated confidence intervals are multiplied by the model predictions, then added together to generate a prediction and range for the number of pilots needed to complete future work assignments given the inputs. Comp days = compensation days, h = hour, MHS = multiple harbor shifts, CI = confidence interval.

There are other schedule factors that were not significant predictors in the statistical model that should also be considered when assessing pilot staffing needs, but the most important variable that was not included in the model was the minimum rest period. The minimum rest period between assignments was changed from eight hours to 10 hours in October 2018. This variable was not a significant predictor in the model, likely because it was not possible to include mean rest period in the model for hypothetical modeling (see methods, the rest period variable was dichotomized and the frequency of rest < 10 h per day was included in the model). There were 1386 instances where pilots received less than 10 hours off following an assignment (including back-to-back callback assignments). The difference between the actual time off and the recommended time off of 10 hours was 2595 hours. This amount of time is equivalent to ~2 pilots per year.

Staffing Requirement Projections

The projected number of pilots needed to fulfill staffing requirements while also minimizing fatiguing work shifts is presented in Table 8. This projection includes the estimates from the linear regression model with adjustments made based on fatigue risk management recommendations. This model also includes the projected number of pilots needed to reduce the bank of compensation time accrued by the pilots and two pilots in rotation to cover future work hour restrictions that could not be modeled.

Projection Variable	Number of Projected Pilots	Projected 95% CI (lower)	Projected 95% CI (upper)
Linear regression estimate	53	39	67
Compensation day coverage	4	4	4
Additional work hour reduction coverage	2	2	2
President	1	1	1
Total	**60***	**46**	**74**

Table 8. Estimated number of pilots needed to cover all shifts while reducing work practices that induce fatigue. *Note that this does not include the pilots needed to account for earned time off.

The total number of pilots needed including earned time off coverage is 63 (60*0.055), with a range from 49-78.

Relationship between Number of Assignments and Staffing Levels

The goal of this analysis was to determine the number of pilots needed to provide board-on-arrival service at the current level of vessel traffic, while minimizing fatigue. The average number of vessels per day was 20.1 for the calendar year dataset (18.65 when MHS are combined into one shift per day). The total number of vessel moves in the calendar year dataset was 7,334. If the recommended number of pilots are hired (63), then each pilot should complete ~116 vessel moves (including the president, ~118 excluding the president).

6 Recommendations

We found that the Puget Sound Pilot work practices are associated with variable and unpredictable workload and work start times, frequent night work, frequent instances of insufficient time off between shifts, and numerous extended-duty work shifts. In addition, current scheduling practices rely heavily on calling pilots back to work during scheduled days off. This leads to an overall increase in the number of days and hours that pilots work in a month and also leads to the accrual of an unsustainable rate of compensation time. Finally, the attrition rate has the potential to out-pace the rate of recruiting and training. Recommendations on each of these factors is provided below. These factors were all considered in estimating the number of pilots that would be needed to cover all work assignments going forward.

Number of Pilots Needed to Cover Assignments

We estimate that the total number of pilots needed to cover all work assignments going forward is 63 (range 49-78). This estimate was derived from modeling the factors associated with work scheduling, including restrictions on work hours in order to minimize fatigue. In addition to model estimates, one pilot was added to account for the President of the Puget Sound Pilots, six pilots were added to cover compensation time and further work hour restrictions, and three were added to cover earned time off.

Extended Duty Work Shifts

The current Puget Sound Pilot scheduling practices allow for multiple harbor shifts of unlimited duration. In the dataset that we evaluated, pilots completed sequence of these short ship duration, short distance ship movements with little time off between each move. Although many of these assignments are short in duration, these moves are often spaced less than six hours apart. When coupled with the unpredictable nature of pilot scheduling, it is unlikely that pilots completing sequences of multiple harbor shifts have adequate time for rest between ship moves. PSP should consider limiting MHS work hours to reduce fatigue. Although it has been proposed that MHS be limited to 13 hours, this work shift may still lead to fatigue. PSP should consider evaluating fatigue during MHS to determine the appropriate limit, which may be less than 13 hours.

Night Work

The Puget Sound Pilots have already implemented a rule that prevents pilots from working more than three night shifts in a row. This change is consistent with fatigue risk management principles.

In the dataset that we evaluated, it was common practice for pilots to complete both the inbound and outbound moves for cruise ship operations. These operations provided a rest opportunity that was typically less than eight hours during the morning. The circadian rhythm promotes wakefulness during the biological day, which can reduce sleep quality and quantity. As a result, we recommend that individual pilots are only assigned inbound and outbound cruise operations when a sufficient rest opportunity is available between the inbound and outbound movements. PSP should also consider evaluating the quality and quantity of sleep obtained between cruise ship operations.

We found numerous instances of night work following a reposition assignment, where a pilot was repositioned to arrive in Port Angeles in the late afternoon, but then was assigned a ship move in the late evening/night. It appears that this stems from the current procedure that allows pilots to “begin work immediately” following any reposition that occurs early in the day. This practice is concerning, because the term “immediate” is not defined, which allows pilots to work many hours after arrival at Port Angeles station. We recommend that reposition assignments be treated in a similar manner to vessel movement assignments, whereby if the reposition assignment and any associated vessel movement assignments be considered a single work shift and be limited in duration. In cases where a reposition assignment is completed and no ship movement can be assigned and completed within the designated timeframe, then the pilot should be provided with a rest opportunity prior to scheduling the next assignment.

Time off Between Assignments

Subsequent to the trailing-12 data considered in this analysis, the Puget Sound Pilots implemented a rule that allowed for 10 hours of rest following work assignments. This amount of time off is consistent with fatigue risk management principles, which support providing workers with enough time off between shifts for eating, personal hygiene routines, and the opportunity for eight hours of sleep.

Callbacks and Compensation Time

The current practice of calling pilots back to work on days off and then providing them with a compensation day is unsustainable with current staffing levels. Additional staff are required in order to deplete the cumulative bank of accrued compensation days and to reduce or eliminate the rate of compensation day accruals. This is particularly important given that many pilots are nearing retirement and will use compensation time and will not be available for work. Going forward, the Puget Sound Pilots should increase staffing levels to eliminate the need for frequent callbacks. In addition, the Puget Sound Pilots may consider putting a limit on the number of callbacks that an individual pilot is required to perform. Similarly, only once when staffing levels are sufficient to minimize the need for callbacks, the Puget Sound Pilots should reevaluate the process for the accrual and use of compensation days.

Meetings

Peak meeting times were on Tuesdays, which is the day when pilots transition between on watch to off watch. This appears to be an appropriate process for conducting meetings while minimizing fatigue and disruption to service.

Retirement and Licensing

The Puget Sound Pilot workforce is aging, with a third of the population either of retirement age or eligible for standard retirement within the next five years. More than half of the pilots are eligible for retirement within 10 years. The current licensing level of the pilots appears to be appropriate for meeting work demands at the present time, with the majority of license holders at license level 5. However, the distribution of age among current pilots is skewed towards retirement and towards the highest license level. As current pilots retire, there may not be enough pilots of an appropriate license level to handle all license levels of ship movements. As a result, we recommend that efforts to recruit and train new pilots be prioritized. It would be worthwhile to conduct a separate evaluation to determine hiring needs to account for the expected attrition rate and license levels going forward.

Validation and Verification of Staffing/Scheduling Changes

Fatigue risk management programs provide a framework for implementing best practices aimed at mitigating the risk of fatigue in operational environments. Although implementation of such measures is intended to reduce the risk of fatigue, every operational environment involves unique challenges that may interact with staffing levels and scheduling changes. As a result, schedule and staffing changes should be evaluated to ensure that such changes do not lead to negative outcomes. Therefore, we recommend that the Puget Sound Pilots implement a fatigue risk management system for continued education of the PSP workforce and for ongoing surveillance of fatigue risk before and after the implementation of any of the changes described in this report. For example, although the Puget Sound Pilots have already pursued work hour restrictions to limit multiple harbor shifts to 13 hours in duration, it is possible that a shorter duration is necessary to promote optimal sleep, alertness, and performance.

7 References

Achermann, P., Werth, E., Dijk, D. J., & Borbely, A. A. (1995). Time course of sleep inertia after nighttime and daytime sleep episodes. *Arch Ital Biol, 134*(1), 109-119. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8919196.

Aisbett, B., & Nichols, D. (2007). Fighting fatigue whilst fighting bushfire: an overview of factors contributing to firefighter fatigue during bushfire suppression. *Australian Journal of Emergency Management, The, 22*(3), 31-39.

Akhtar, M. J., & Utne, I. B. (2014). Human fatigue's effect on the risk of maritime groundings–A Bayesian Network modeling approach. *Safety science, 62*, 427-440.

Angus, R. G., & Heslegrave, R. J. (1985). Effects of sleep loss on sustained cognitive performance during a command and control simulation. *Behavior Research Methods, Instruments, & Computers, 17*(1), 55-67.

Barger, L. K., Cade, B. E., Ayas, N. T., Cronin, J. W., Rosner, B., Speizer, F. E., . . . Safety, G. (2005). Extended work shifts and the risk of motor vehicle crashes among interns. *N Engl J Med, 352*(2), 125-134. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15647575. doi:10.1056/NEJMoa041401

Basner, M., & Dinges, D. F. (2009). Dubious bargain: trading sleep for Leno and Letterman. *Sleep, 32*(6), 747-752. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/19544750.

Belenky, G., Wesensten, N. J., Thorne, D. R., Thomas, M. L., Sing, H. C., Redmond, D. P., . . . Balkin, T. J. (2003). Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: a sleep dose-response study. *J Sleep Res, 12*(1), 1-12. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12603781.

Burke, T. M., Scheer, F. A., Ronda, J. M., Czeisler, C. A., & Wright, K. P., Jr. (2015). Sleep inertia, sleep homeostatic and circadian influences on higher-order cognitive functions. *J Sleep Res*. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/25773686. doi:10.1111/jsr.12291

Czeisler, C. A., & Gooley, J. J. (2007). Sleep and circadian rhythms in humans. *Cold Spring Harb Symp Quant Biol, 72*, 579-597. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/18419318. doi:10.1101/sqb.2007.72.064

Czeisler, C. A., Weitzman, E., Moore-Ede, M. C., Zimmerman, J. C., & Knauer, R. S. (1980). Human sleep: its duration and organization depend on its circadian phase. *Science, 210*(4475), 1264-1267. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/7434029.

Dawson, D., & Reid, K. (1997). Fatigue, alcohol and performance impairment. *Nature, 388*(6639), 235. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9230429. doi:10.1038/40775

Dijk, D. J., & Czeisler, C. A. (1994). Paradoxical timing of the circadian rhythm of sleep propensity serves to consolidate sleep and wakefulness in humans. *Neurosci Lett, 166*(1), 63-68. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8190360.

Dijk, D. J., Duffy, J. F., & Czeisler, C. A. (1992). Circadian and sleep/wake dependent aspects of subjective alertness and cognitive performance. *Journal of Sleep Research, 1*(2), 112-117.

Dijk, D. J., & von Schantz, M. (2005). Timing and consolidation of human sleep, wakefulness, and performance by a symphony of oscillators. *J Biol Rhythms, 20*(4), 279-290. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/16077148. doi:10.1177/0748730405278292

Ferguson, S. A., Baker, A. A., Lamond, N., Kennaway, D. J., & Dawson, D. (2010). Sleep in a live-in mining operation: the influence of start times and restricted non-work activities. *Applied Ergonomics, 42*(1), 71-75.

Filor, C. W. (1998). Things that go bump in the night – Fatigue at sea. In L. R. Hartley (Ed.), *Proceedings of the Third International Conference on Fatigue and Transportation. Feb* (pp. 9-13). Freemantle, Australia: Elsevier.

Flynn-Evans, E. E., Arsintescu, L., Gregory, K., Mulligan, J., Nowinski, J., & Feary, M. (2018). Sleep and neurobehavioral performance vary by work start time during non-traditional day shifts. *Sleep Health, 4*(5), 476-484. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/30241664. doi:10.1016/j.sleh.2018.08.002

Flynn-Evans, E. E., Tabandeh, H., Skene, D. J., & Lockley, S. W. (2014). Circadian Rhythm Disorders and Melatonin Production in 127 Blind Women with and without Light Perception. *J Biol Rhythms, 29*(3), 215-224. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/24916394. doi:10.1177/0748730414536852

Folkard, S. (1997). Black times: temporal determinants of transport safety. *Accident Analysis & Prevention, 29*(4), 417-430.

Folkard, S. (1999). *Transport: Rhythm and Blues: The 10th Westminster Lecture on Transport Safety*. Retrieved from London, England:

Folkard, S., Lombardi, D. A., & Spencer, M. B. (2006). Estimating the circadian rhythm in the risk of occupational injuries and accidents. *Chronobiol Int, 23*(6), 1181-1192. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/17190704. doi:10.1080/07420520601096443

Folkard, S., Lombardi, D. A., & Tucker, P. T. (2005). Shiftwork: safety, sleepiness and sleep. *Industrial health, 43*(1), 20-23.

Folkard, S., & Tucker, P. (2003). Shift work, safety and productivity. *Occupational medicine, 53*(2), 95-101.

Guidelines on Fatigue. (2001). Retrieved from London, England:

Hilditch, C. J., Centofanti, S. A., Dorrian, J., & Banks, S. (2016). A 30-Minute, But Not a 10-Minute Nighttime Nap is Associated with Sleep Inertia. *Sleep, 39*(3), 675-685. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/26715234.

Hilditch, C. J., Dorrian, J., Centofanti, S. A., Van Dongen, H. P., & Banks, S. (2017). Sleep inertia associated with a 10-min nap before the commute home following a night shift: A laboratory simulation study. *Accid Anal Prev, 99*(Pt B), 411-415. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/26589387. doi:10.1016/j.aap.2015.11.010

Hirshkowitz, M., et al. (2015). National Sleep Foundation's sleep time duration recommendations: methodology and results summary. *Sleep Health, 1*, 40-43.

Hobbs, A., Gregory, K., Parke, B., Pradhan, S., Caddick, Z., Bathurst, N., & Flynn-Evans, E. (2018). *San Francisco Bar Pilot Fatigue Study* (NASA/TM-2018-219943). Retrieved from Moffett Field, CA:

Horne, J. A., Brass, C. G., & Petitt, A. N. (1980). Circadian performance differences between morning and evening 'types'. *Ergonomics, 23*(1), 29-36.

Horne, J. A., & Ostberg, O. (1976). A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. *Int J Chronobiol, 4*(2), 97-110. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/1027738.

Hursh, S. R., Balkin, T. J., Miller, J. C., & Eddy, D. R. (2004). *The Fatigue Avoidance Scheduling Tool: Modeling to Minimize the Effects of Fatigue on Cognitive Performance*. Paper presented at the Digital Human Modeling for Design and Engineering Symposium, Rochester, MI.

Hursh, S. R., Balkin, T. J., & Van Dongen, H. P. (2017). Sleep and performance prediction modeling. In M. H. Kryger & W. C. Dement (Eds.), *Principles and practice of sleep medicine* (6 ed., pp. 689-696). Philadelphia, PA: Elsevier.

Jewett, M. E., Wyatt, J. K., Ritz-De Cecco, A., Khalsa, S. B., Dijk, D. J., & Czeisler, C. A. (1999). Time course of sleep inertia dissipation in human performance and alertness. *J Sleep Res, 8*(1), 1-8. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10188130.

Kang, K., Seo, J.-G., Seo, S.-H., Park, K.-S., & Lee, H.-W. (2014). Prevalence and related factors for high-risk of obstructive sleep apnea in a large Korean population: results of a questionnaire-based study. *Journal of Clinical Neurology, 10*(1), 42-49.

Krueger, P. M., & Friedman, E. M. (2009). Sleep duration in the United States: a cross-sectional population-based study. *Am J Epidemiol, 169*(9), 1052-1063. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/19299406. doi:10.1093/aje/kwp023

Lombardi, D. A., Folkard, S., Willetts, J. L., & Smith, G. S. (2010). Daily sleep, weekly working hours, and risk of work-related injury: US National Health Interview Survey (2004–2008). *Chronobiology international, 27*(5), 1013-1030.

Luckhaupt, S. E., Tak, S., & Calvert, G. M. (2010). The prevalence of short sleep duration by industry and occupation in the National Health Interview Survey. *Sleep, 33*(2), 149-159. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/20175398.

Marcus, J. H., & Rosekind, M. R. (2016). Fatigue in transportation: NTSB investigations and safety recommendations. *Inj Prev*. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/26929259. doi:10.1136/injuryprev-2015-041791

McCallum, M. C., Raby, M., & Rothblum, A. M. (1996). *Procedures for Investigating and Reporting Human Factors and Fatigue Contributions to Marine Casualties*. Retrieved from Washington, DC:

Minding the Helm: Marine Navigation and Piloting (030904829X). (1994). Retrieved from Washington, DC:

Minors, D., & Waterhouse, J. (1985). Circadian rhythms in deep body temperature, urinary excretion and alertness in nurses on night work. *Ergonomics, 28*(11), 1523-1530.

Mitler, M. M., Carskadon, M. A., Czeisler, C. A., Dement, W. C., Dinges, D. F., & Graeber, R. C. (1988). Catastrophes, sleep, and public policy: consensus report. *Sleep, 11*(1), 100-109. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/3283909.

Moreno, C., Carvalho, F., Lorenzi, C., Matuzaki, L., Prezotti, S., Bighetti, P., . . . Lorenzi-Filho, G. (2004). High risk for obstructive sleep apnea in truck drivers estimated by the Berlin questionnaire: prevalence and associated factors. *Chronobiology international, 21*(6), 871-879.

Puget Sound Pilots. (2019). Retrieved from https://www.pspilots.org/our-mission/

Puget Sound Pilots Website. (2019). Retrieved from https://www.pspilots.org

Reid, K. J., Turek, F. W., & Zee, P. C. (2016). *Enhancing Sleep Efficiency on Vessels in the Tug/towboat/barge Industry* (0309374987). Retrieved from Washington, DC:

Ribak, J., Ashkenazi, I. E., Klepfish, A., Avgar, D., Tall, J., Kallner, B., & Noyman, Y. (1983). Diurnal rhythmicity and Air Force flight accidents due to pilot error. *Aviat Space Environ Med, 54*(12 Pt 1), 1096-1099. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/6686440.

Rosekind, M. R. (2005). Managing work schedules: an alertness and safety perspective. In K. T. Roth & W. C. Dement (Eds.), *Principles and Practice of Sleep Medicine* (4 ed., pp. 680-690). Philadelphia, PA: Saunders Company.

Ruggiero, J. S., & Redeker, N. S. (2014). Effects of napping on sleepiness and sleep-related performance deficits in night-shift workers: a systematic review. *Biol Res Nurs, 16*(2), 134-142. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/23411360. doi:10.1177/1099800413476571

Sanquist, T. F., Raby, M., Maloney, A. L., & Carvalhais, A. B. (1996). *Fatigue And Alertness In Merchant Marine Personnel: A Field Study Of Work And Sleep Patterns*. Retrieved from Seattle, Washington:

Santhi, N., Horowitz, T. S., Duffy, J. F., & Czeisler, C. A. (2007). Acute sleep deprivation and circadian misalignment associated with transition onto the first night of work impairs visual selective attention. *PLoS One, 2*(11), e1233. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/18043740. doi:10.1371/journal.pone.0001233

Scheer, F. A., Shea, T. J., Hilton, M. F., & Shea, S. A. (2008). An endogenous circadian rhythm in sleep inertia results in greatest cognitive impairment upon awakening during the biological night. *J Biol Rhythms, 23*(4), 353-361. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/18663242. doi:10.1177/0748730408318081

Smith, K. A. (2014, Decembet 2014). West Coast Pilots: New Ships, Old Challenges. *Pacific Maritime Magazine: Marine Business for the Operations Sector*, 24-28. Retrieved from http://pspilots.org/wp-content/uploads/2014/12/pmm-12-2014.pdf

Smith, M. R., & Eastman, C. I. (2012). Shift work: health, performance and safety problems, traditional countermeasures, and innovative management strategies to reduce circadian misalignment. *Nature and science of sleep, 4*, 111-132.

Starren, A., van Hooff, M., Houtman, I., Buys, N., Rost-Ernst, A., Groenhuis, S., & Dawson, D. (2008). *Preventing and managing fatigue in the shipping industry* Retrieved from Hoofddorp, The Netherlands:

Strauch, B. (2015). Investigating fatigue in marine accident investigations. *Procedia Manufacturing, 3*, 3115-3122.

Tassi, P., & Muzet, A. (2000). Sleep inertia. *Sleep Medicine Reviews, 4*(4), 341-353.

Van Dongen, H. P., Maislin, G., Mullington, J. M., & Dinges, D. F. (2003). The cumulative cost of additional wakefulness: dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. *Sleep, 26*(2), 117-126. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12683469.

Washington state pilotage final report and recommendations. (2018). Retrieved from Seattle, WA:

Watson, N. F., Badr, M. S., Belenky, G., Bliwise, D. L., Buxton, O. M., Buysse, D., . . . Tasali, E. (2015). Recommended Amount of Sleep for a Healthy Adult: A Joint Consensus Statement of the American Academy of Sleep Medicine and Sleep Research Society. *Sleep, 38*(6), 843-844. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/26039963. doi:10.5665/sleep.4716

Wertz, A. T., Ronda, J. M., Czeisler, C. A., & Wright, K. P. (2006). Effects of sleep inertia on cognition. *JAMA, 295*(2), 159-164.

Wickens, C. D., Hutchins, S. D., Laux, L., & Sebok, A. (2015). The impact of sleep disruption on complex cognitive tasks: a meta-analysis. *Human Factors, 57*(6), 930-946.

Wickens, C. D., Laux, L., Hutchins, S., & Sebok, A. (2014). *Effects of sleep restriction, sleep inertia, and overload on complex cognitive performance before and after workload transition: a meta analysis and two models.* Retrieved from Proceedings of the Human Factors and Ergonomics Society Annual Meeting

Young, T., Palta, M., Dempsey, J., Skatrud, J., Weber, S., & Badr, S. (1993). The occurrence of sleep-disordered breathing among middle-aged adults. *New England Journal of Medicine, 328*(17), 1230-1235.

Young, T., Shahar, E., Nieto, F. J., Redline, S., Newman, A. B., Gottlieb, D. J., . . . Samet, J. M. (2002). Predictors of sleep-disordered breathing in community-dwelling adults: the Sleep Heart Health Study. *Archives of internal medicine, 162*(8), 893-900.