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SPECIAL ARTICLE

Guiding principles for determining work shift duration and addressing the effects of work shift duration on performance, safety, and health: guidance from the American Academy of Sleep Medicine and the Sleep Research Society

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Abstract

Risks associated with fatigue that accumulates during work shifts have historically been managed through working time arrangements that specify fixed maximum durations of work shifts and minimum durations of time off. By themselves, such arrangements are not sufficient to curb risks to performance, safety, and health caused by misalignment between work schedules and the biological regulation of waking alertness and sleep. Science-based approaches for determining shift duration and mitigating associated risks, while addressing operational needs, require: (1) a recognition of the factors contributing to fatigue and fatigue-related risks; (2) an understanding of evidence-based countermeasures that may reduce fatigue and/or fatigue-related risks; and (3) an informed approach to selecting workplace-specific strategies for managing work hours. We propose a series of guiding principles to assist stakeholders with designing a shift duration decision-making process that effectively balances the need to meet operational demands with the need to manage fatigue-related risks.

Statement of Significance

There is a critical need for policies and regulations regarding shift duration to reliably manage risks related to fatigue and sleepiness in the workplace. Regulators, organizations, communities, and workers often struggle with how to manage shift duration and address associated risks from fatigue and sleepiness while continuing to meet the societal demands for work. Scientific evidence that is essential for designing effective shift duration solutions has grown substantially in recent years, and global practices have evolved, providing a foundation for making informed decisions about shift duration while preserving the integrity and feasibility of workplace operations. We present an ensemble of guiding principles, with reference to relevant resources and examples, to help devise tailored solutions pertaining to shift duration.

Key words: working time arrangements; shift scheduling; mental fatigue; sleepiness; alertness; productivity; circadian rhythms; sleep homeostasis; occupational medicine; policy making

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Definitions: Fatigue, Sleepiness, and Alertness

Science-based approaches for determining shift duration and mitigating associated risks are based, in part, on literature about sleep, sleep deprivation, circadian rhythmicity (i.e. timing on the biological clock in the brain), and the concepts of *fatigue*, *sleepiness*, and *alertness*. In the scientific literature, a variety of definitions for *fatigue*, *sleepiness*, and *alertness* can be found [1–3]. In clinical and academic settings these terms have distinct meanings [3], with *fatigue* often used to refer to bodily symptoms associated with physical exertion, medical conditions such as anemia, thyroid disease, or cancer, and use of medications, such as blood pressure-lowering drugs or chemotherapy. In these settings, *fatigue* is not generally used in relation to insufficient or displaced sleep. In operational contexts, however, the terms *fatigue*, *sleepiness*, and *reduced alertness* are often used interchangeably [3–5]. To avoid confusion, the terminology used in this paper is based on the following definitions, which are typical in practice across operational settings.

Fatigue: A state of reduced mental or physical performance capability, resulting from sleep loss or extended wakefulness, circadian rhythmicity, workload, or other factors [6]. As used in operational settings, *fatigue* manifests as performance impairment when engaging in a task. *Mental fatigue* implies decreased or degraded cognitive performance; *physical fatigue* implies decreased or degraded physical performance.

Sleepiness: A state of increased tendency to fall asleep, resulting from sleep loss or extended wakefulness, circadian rhythmicity, medications, or various sleep disorders [2, 3]. *Sleepiness* manifests objectively as an increased likelihood to fall asleep rapidly [2], and subjectively as an increased need or desire to sleep [3]. *Sleepiness* is a contributor to *mental fatigue* [3, 5].

Alertness: The ability to direct and sustain attention, which is influenced by prior sleep and sleep loss, circadian rhythmicity, time on task (duration of continuous work), and other factors [7]. *Alertness* manifests as the ability to maintain the attention necessary to perform a task at a specified level. *Sleepiness* is associated with *reduced alertness* [2].

Introduction

The scheduling of work shifts has historically prioritized productivity, taking into account production costs and the available human resource pool, with little consideration of the effects of work schedules on workers [8]. While acknowledging the importance of productivity, mounting evidence indicates that work schedules can have a negative impact on workers and their communities [9, 10]. The need to balance a demand for high work productivity at all hours of the day with the costs associated with long work hours fuels debate among employers, workers and policymakers about what the maximum durations of work shifts should be. This debate is complex, and a single solution would not be applicable to all work settings, industries or occupations.

During the 19th and part of the 20th century, when most work involved physical labor, the debate focused on physical fatigue as the main concern for work performance and safety. Because physical fatigue accumulates steadily across the duration of physical work, and dissipates progressively during rest breaks, regulations to limit fatigue focused on prescribing maximum durations for work shifts and minimum durations for time off [11]. After World War II, the focus shifted from physical fatigue to mental fatigue as the primary concern in most industries [12]. While mental fatigue, like physical fatigue, is exacerbated with increased work duration and reduced by rest breaks, mental fatigue does not simply accumulate and dissipate progressively with time on and off work [13]. Other factors—especially time of day and the durations of wakefulness and prior sleep (see Appendix A)—also have a significant effect on mental fatigue [5]. Nonetheless, regulations for shift duration are typically prescriptive and focused on shift maxima and break minima, along with limits on work hours aggregated over weeks to months.

Following deregulation efforts in the 1980s, many industries moved toward longer shifts and greater demands at work. Many factors contributed to this trend [14, 15], including increased global competition; shortage of qualified employees; increased overtime and secondary employment to maintain a standard of living; increasing economic disparities; rising healthcare and retirement costs; and contingent work arrangements such as contract work. These trends have persisted into the 21st century. According to data from the American Time Use Survey in 2017 and 2018, 16% of U.S. wage and salary workers have

non-standard working time arrangements [16] under a wide range of prevailing practices and regulations. Based on the 2019 Current Population Survey, 16.3% of the U.S. labor force works 49 h or more per week, and 6.6% works at least 60 h per week [17].

Working longer hours has yielded economic prosperity and, on average, a higher standard of living, but has also resulted in increased levels of risk related to mental fatigue [11]. Productivity requirements and financial incentives to work have grown substantially [15, 18]. Work hours are distributed increasingly across all hours of the day and infringe on the “biological night,” that is, the time period when the biological clock signals to the brain that it is time to sleep [19]. Increasingly, work hours curtail the opportunity to obtain adequate sleep, with approximately 40% of workers in several major occupational sectors reporting short sleep duration [20]. Other factors such as long commute times, skipped rest breaks, insufficiently regulated overtime, multiple jobs, caregiver duties, and social commitments also contribute to mental fatigue [5, 21–24].

Mental fatigue is associated with considerable risks to employees, employers, and society at large [5, 9]. Acute, short-term risks include reductions in performance, effectiveness, and productivity [5, 25, 26]; increased errors and do-overs [26, 27]; absenteeism [24, 28]; “presenteeism,” wherein the worker is on task but performing below capacity [26, 28]; ineffective teamwork [29]; immoral or unethical behavior [30, 31]; reduced job satisfaction [32]; degraded quality of life [33, 34]; decreased morale [29]; reduced safety [35, 36]; workplace accidents and injuries [4, 37–39]; motor vehicle crashes during the commute [40]; and high-profile industrial catastrophes [41, 42]. In addition to degraded physical and mental health [43], long-term risks include reduced individual and community well-being as well as economic losses [44]. Adverse fatigue-related outcomes are typically under-reported and under-recognized [45], and systematic approaches to attributing the causes of these outcomes to work schedules [46, 47] are not widely used. While exact figures of the costs to society associated with fatigue are therefore not available, estimates for the United States exceed \$100 billion annually [26].

Mental fatigue is determined in large measure by time of day and the durations of wakefulness and prior sleep [48] (see Appendix A). Prescriptive regulations for shift maxima and

break minima alone are, therefore, not a dependable means of ensuring adequate sleep and/or mitigating risks associated with mental fatigue [49, 50]. In other words, the effectiveness of a rule set with fixed thresholds that restrict shift duration and protect time off depends on the circumstances. Such a rule set does not necessarily address fatigue and fatigue-related risks adequately and reliably, and the promulgation of such a rule set by a regulator should not be taken as a determination that work hours compliant with the rule set are automatically safe [11]. Despite decades of implementation efforts and debate, no consensus exists on an appropriate maximum shift duration [51]. Prescriptive regulations for work hours and rest can be effective to prevent work schedules that maximize productivity with no consideration for the biological need for sleep and other prerequisites for safety and health. However, prescriptive regulations alone are not the solution, and sometimes they can be counterproductive [52]. Many work environments with prescriptive working time regulations show poor congruence between regulatory compliance and risk outcomes. On the one hand, a primary emphasis on productivity within the constraints of regulatory compliance incentivizes the creation of shift schedules that leave risks associated with fatigue/sleepiness poorly addressed. On the other hand, prescriptive regulations for work hours and rest do little to curb the long-term health risks associated with workers not getting enough sleep on a regular basis. Furthermore, some prescriptive regulations may involve limits from which even minor deviations to improve relevant outcomes such as productivity or worker well-being may be prohibited despite negligible increases in fatigue/sleepiness-related risks. If congruence between compliance with regulations and outcomes is poor, it threatens both the effectiveness of those regulations and the willingness of individuals and organizations to adhere to them, with potentially harmful consequences [11].

A well-recognized need exists, therefore, for policies and regulations regarding shift duration that curb fatigue/sleepiness-related risks reliably. However, regulators, organizations, communities and workers often struggle with how to manage shift duration and manage fatigue/sleepiness-related risks while continuing to meet the societal demands for work. Guiding principles that inform policy and decision-making in this area have been difficult to access, so stakeholders are often put in a position of addressing work schedule issues with insufficient guidance. Industrial and regulatory agreements pertaining to shift duration should not be taken at face value as evidence of acceptable risk levels. Scientific evidence that is essential for designing effective shift duration solutions has grown substantially in recent years [8], and global practices have evolved [53, 54]. The evidence that is now available can help inform decisions about shift duration and timing, while also addressing the integrity and feasibility of workplace operations.

This document is a guide to help devise tailored solutions pertaining to shift duration. We present this information as an ensemble of guiding principles, with reference to relevant resources and examples. The guiding principles consider scientific evidence, values- and ethics-based contexts, goals and objectives of organizations and individuals, resource needs, and feasibility. Taken together, the guiding principles represent a framework from which decisions can be made. We encourage stakeholders – managers and their representatives, employees and their representatives, legislators, policy makers, and occupational medicine professionals – to consider the guiding

principles, collectively (rather than separately), in designing effective, context-specific solutions regarding shift duration.

Risk Factors Associated with Shift Duration

While the mechanisms linking shift duration with health outcomes remain unclear [55], the relationship between shift duration and performance and safety outcomes is relatively well-understood. Work hours control the duration and timing of wakefulness and constrain the duration and timing of sleep, which affects the manifestation of mental fatigue, which in turn influences performance—including physical [56], mental [57], leadership [58], and team-based [29]—and safety risks [59, 60]. The relationship of wakefulness and sleep with fatigue is mediated by sleepiness, which is governed by two primary biological processes: the “circadian” wake drive and the “homeostatic” sleep drive [61]. The “circadian” process promotes wakefulness during the day and sleep during the night, as driven by the brain’s biological clock. The “homeostatic” process seeks to balance the amounts of wakefulness and sleep by increasing sleep pressure as time awake accrues, and dissipating sleep pressure as time asleep accrues. At any given time during wakefulness, the interplay between these two processes determines sleepiness and thereby influences the level of mental fatigue (see [Appendix A](#)) [48, 62].

The manifestation of fatigue related to sleepiness driven by the two processes is exacerbated when working time arrangements limit and/or displace the time available for sleep [5]. Other demands on a person’s time, including time needed for eating, personal hygiene, commuting, caregiver responsibilities, social activities, educational activities, secondary job, etc., may further constrain the time available for sleep and increase sleepiness and fatigue [23, 24, 63, 64]. Furthermore, the effects of repeated exposure to sleep loss and/or sleep displacement across consecutive days are cumulative [65, 66]. In the workplace, other factors, such as workload [67], stress [28, 68], and inherent workplace hazards [69, 70] interact with fatigue/sleepiness to determine the overall fatigue-related risk levels associated with shift duration [5] (see [Figure 1](#)). Collectively, these risk factors are captured in guiding principles 1.1–1.3 below.

Guiding principle 1.1: The duration of work shifts is linked to adverse performance, safety, and health outcomes, especially when the shifts are not aligned with a worker’s biological clock to promote alertness during work and sleep during time off.

A primary cause of adverse outcomes associated with shift duration is misalignment of the timing and duration of work hours with the innate physiologic, temporal regulation of sleep and waking alertness [10, 71]. If sleep occurs during the night, when the circadian drive for wakefulness is low, and wakefulness and work occur during the day, when the circadian drive for wakefulness is high, the recuperative potential of sleep is generally high, and alertness during work hours is expected to be optimal. However, deviation of work hours from this optimal alignment may compromise the recuperative effect of sleep and increase sleepiness while awake, which contributes to mental fatigue and increased risk of adverse performance, safety and health outcomes [72, 73].

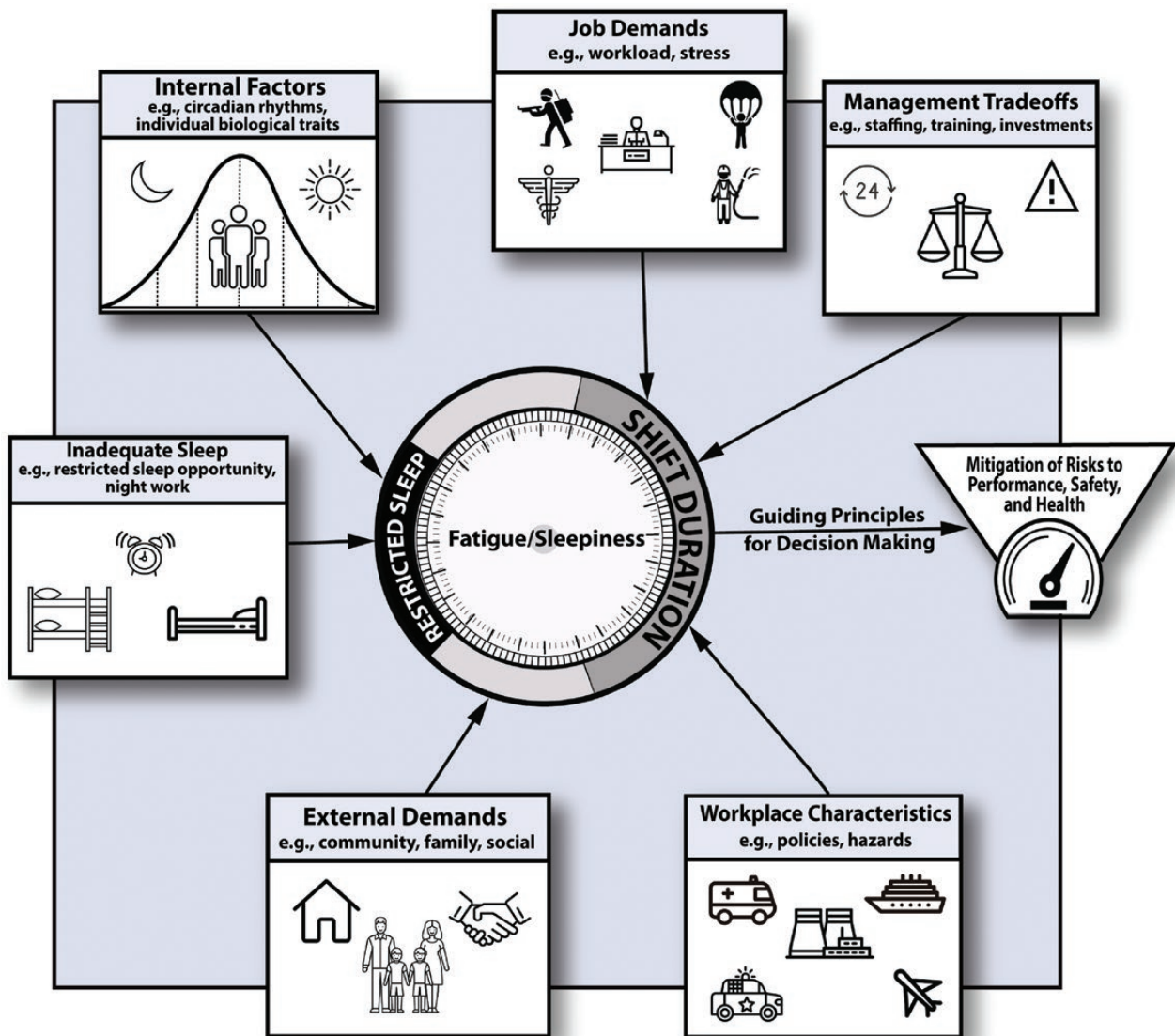


Figure 1. Factors influencing the performance, safety and health risks associated with shift duration. This diagram illustrates the multiple factors to be considered in balancing the needs of an operational setting, the human resource requirements to meet those needs, and the pivotal and complex role of shift duration. Shift duration competes with other demands on people's time—for example, for commuting, eating, personal hygiene, non-work-related commitments, and social activities—and restricts the time available for sleep [23, 24, 63]. Fatigue/sleepiness associated with reduced and displaced sleep and with the timing of the biological clock (circadian rhythm), in conjunction with individual traits (e.g. vulnerability to sleep loss) and workplace characteristics and hazards determines overall risk levels [124, 144]. Evaluation of these interconnected factors is pertinent to decision making about shift duration.

Although long work hours may cause fatigue due to the duration of continuous work alone, this effect is exacerbated when the work period causes the duration of wakefulness to be extended, such that the build-up of pressure for sleep from the homeostatic process increases, and/or pushes some of the work hours into the night, when the circadian drive for wakefulness is low. Such working time arrangements place work hours at times when sleepiness, and therefore mental fatigue, is intrinsically increased [5]. They may also infringe on time available for sleep, thereby reducing the restorative effects of sleep for alertness, performance, safety, and health [23].

For example, a professional driver may have an early morning duty start and then face traffic delays toward the end of the shift. Such a work schedule extends the waking period into the evening hours and may lead to sleepiness and contribute to

fatigue, which could lead to errors and accidents [74]. Fatigue/sleepiness and related risks would be compounded by a night shift schedule, where the work period may end at a time when accumulated homeostatic pressure for sleep and reduced pressure for wakefulness from the biological clock act together to increase sleepiness coincident with the time of the commute home after work [40].

Risks associated with fatigue/sleepiness are also compounded by chronic exposure to sleep loss or sleep displacement [65, 66, 75], and multiple days with recovery sleep may be needed to overcome the cumulative effects of sustained sleep insufficiency [65]. Moreover, when sleep is chronically insufficient, self-monitoring of fatigue/sleepiness becomes less reliable [66, 76]. These issues are problematic in work schedules that cause sleep to be curtailed routinely, and emphasize the importance

of offsetting even occasional sleep loss (e.g. to handle a work-related emergency) with ample recovery sleep opportunity in order to avoid risk accumulation.

Guiding principle 1.2: Work-related factors, such as workload and commute time, contribute to the impact of shift duration on performance, safety, and health outcomes.

Whereas the alignment of work hours with respect to the temporal regulation of sleep and waking alertness is the primary driver of performance, safety and health outcomes, a variety of other work-related factors also play a role. These include schedule configuration considerations, such as early starts [77], forward and (especially) backward rotating shifts [78, 79], irregular shift schedules [72], quick returns [80], work breaks [81], number of consecutive shifts [82], time off between duty cycles [76, 83], and cumulative work hours across weeks, months and years [54]—and the frequency and extent to which these factors occur alone or in combination. Furthermore, working conditions play a role, including physical, cognitive and/or emotional workload [84–87], environmental conditions [5], inherent hazard exposure [88], and workplace culture and policies [89–93].

Commutes to and from work impose a demand on workers and may curtail sleep opportunity [63, 94]. As such, the duration of the commute, its timing, traffic exposure, and road, weather and light conditions are all relevant. The time required for commuting and other work-related time commitments outside of work (e.g. time to prepare and wind down from work) may accumulate to a degree that, combined with the work shift, leaves insufficient time for sleep and recuperation. For example, a worker who completes a 12-h shift preceded and followed by a 2-h commute, after managing activities of daily living (e.g. eating, personal hygiene), would have insufficient time between shifts to get adequate sleep.

These factors result in a demand on workers to manage extended hours of operation, often under conditions of circadian misalignment associated with shift work and with chronic restriction of sleep opportunities [9]. This scenario affects or destabilizes the health and wellness of the worker [10]. Depending on the operational setting and context, responsibility for addressing these factors may rest with employers, employees, regulators, or other stakeholders [11].

Guiding principle 1.3: Biological, behavioral, and social factors contribute to the impact of shift duration on performance, safety, and health outcomes.

The impact of shift duration, shift schedules, and other work-related factors on performance, safety and health outcomes is moderated by biological, behavioral and social factors that influence sleep need, optimal sleep timing, response to sleep loss, tolerance to operating long hours, and overall resilience [95]. The direction of the effects, whether protective or not, may vary within and between factors, and depends on the context.

Among the most impactful of these factors is “chronotype,” which represents the individual preference, partially biologically mediated, to be active early or late in the day and to sleep

early or late in the night [96]. Chronotype determines the optimal timing of sleep, and therefore the extent to which work hours may fall outside the alert waking hours and/or interfere with sleep [97]. Individuals also vary in how well they tolerate work hours that are poorly aligned with their chronotype [98]. Other relevant individual characteristics, most of which have been identified in the context of shift work, include age [99], sex [100], race/ethnicity [101], physical fitness [99], physical and mental health status [101], vulnerability to sleep loss [102], sensitivity to stress [103], and coping style [104]. Social moderators such as family-related, cultural, societal, and socioeconomic factors are also relevant [9].

Enduring or extended exposure to risk factors, whether biological, behavioral, individual, or societal, is likely to confer greater risk of adverse long-term consequences, compared against brief or short-term exposure. For example, there are well-documented risks to long-term health [105] from sleeping during the day, at irregular times, or insufficiently [73]; sleeping at least 7 h per night is recommended for the average adult [106]. Epidemiologic studies of night shift work suggest that long-term health risks accumulate with the number of years of shift work exposure [10]. The extent to which cumulative health risks are specifically a function of shift duration remains to be determined, but shared biological mechanisms underlying the impacts of shift duration and the duration and timing of sleep (see Appendix A) suggest that shift duration plays a role.

Countermeasures for Risks Associated with Shift Duration

Tools and strategies that can be deployed in operational settings to reduce the adverse consequences of extended work shifts, collectively called “countermeasures,” are an integral component of mitigating the impact of work hours on performance, safety, and health [60, 81]. Although relatively little is known about countermeasures that pertain to health specifically, much more is known about countermeasures relevant to performance and safety or risks overall. Countermeasures that are backed by evidence of their effectiveness, at least in the short term, and generally expected to be feasible and acceptable to workers are summarized in Table 1. Because of their potential to offset the risks associated with work hours, the availability and implementation of countermeasures is an important consideration when discussing shift duration [5].

Some countermeasures reduce shift duration-related risks by increasing the amount of sleep or raising the level of waking alertness [107, 108]. Other countermeasures target operational risk outcomes; examples include checklists, quality control checks, warning systems, and team-based work strategies [69, 91]. Regardless of the approach, the goal is to manage fatigue/sleepiness-related performance, safety and health outcomes associated with shift duration [60]. The list of countermeasures in Table 1 is not meant to be exhaustive. Additional, context-specific countermeasures may be available for particular occupations (e.g. a wake-up call program for pilots taking advantage of nap opportunities while waiting for cargo planes to be loaded [109]).

For the implementation of a given countermeasure, the benefits of decreasing fatigue/sleepiness or improving outcomes must be weighed against any unintended consequences.

Table 1. Countermeasures for risks associated with shift duration. The table lists countermeasures that have evidence of their effectiveness, at least in the short term, and are generally expected to be feasible and acceptable to workers. See [Appendix D](#) for background information and references

Counter-measure	Timing of use			Short-term effects	Long-term effects
	Before shift	During shift	After shift		
Scheduling interventions to: <ul style="list-style-type: none"> maximize daily sleep opportunity consistently align work with the biological drive for wakefulness increase time for recovery after extended duties or multiple shifts (see Appendix D1) 	Providing employees with advance notice of working time arrangements allows for better preparation for a work shift (e.g. preparatory napping)	In shift work and extended shift operations, implementations of fixed (non-rotating) or forward rotating shift schedules, shorter shift durations, and reduced workload may constitute improvements Scheduling enough personnel to allow for rest breaks during work shifts facilitates the use of other countermeasures such as workplace napping, strategic caffeine use, and activity breaks	Providing employees with adequate time off between shifts allows for greater recovery	Positive effects: <ul style="list-style-type: none"> improved alertness and performance on the job greater team effectiveness higher job satisfaction and quality of life less absenteeism and presenteeism reduced errors and accidents Negative effects: <ul style="list-style-type: none"> possible unintended impact on other personnel 	Positive effects: <ul style="list-style-type: none"> better health outcomes greater community well-being potentially higher economic gains Negative effects: <ul style="list-style-type: none"> possible impact on other operations and community services possible unintended consequences for family and community
Napping (see Appendix D2)	Napping may be used to reduce sleep pressure before evening or night work (“prophylactic napping”)	Sanctioned workplace napping (on-the-job napping) can help alleviate unexpected sleepiness or sleepiness arising from extended shift duration	Napping may be advisable after a night or early morning shift to catch up on sleep or revert to a nighttime sleep schedule	Positive effects: <ul style="list-style-type: none"> improved alertness and performance on the job, during the commute, and/or at home Negative effects: <ul style="list-style-type: none"> sleep inertia, which is significantly reduced alertness and performance immediately upon waking, requiring a brief period (15–30 min) to reorient before engaging in work tasks or driving 	Positive effects: <ul style="list-style-type: none"> not well established Negative effects: <ul style="list-style-type: none"> not well established
Caffeine use (see Appendix D3)	Caffeine use may be advisable before an extended commute to work or a long shift	Frequent, low-dose caffeine use may stabilize alertness and performance after sleep loss and during night and early morning shifts If consumed close to intended sleep time, caffeine can interfere with sleep onset	Caffeine use may be advisable before an extended commute home	Positive effects: <ul style="list-style-type: none"> improved alertness and performance on the job, during the commute, and/or at home when taken in conjunction with a nap, the time to overcome sleep inertia (see under “napping” above) may be reduced Negative effects: <ul style="list-style-type: none"> large inter-individual differences in caffeine effectiveness and tolerance make it difficult to provide tailored advice on caffeine use 	Positive effects: <ul style="list-style-type: none"> not well established Negative effects: <ul style="list-style-type: none"> habituation to caffeine can reduce its effectiveness sustained, high-dose caffeine use can cause side effects (e.g. anxiety, insomnia, tremor, arrhythmias, dehydration, withdrawal headaches)
Sleep hygiene and treatment of sleep disorders (see Appendix D4)	Sleep hygiene strategies may be used before a shift to help maximize sleep duration and improve the recuperative potential of sleep	Sleep hygiene strategies may be used to optimize benefit from on-the-job napping	Diagnosis and treatment of sleep disorders improves sleep’s recuperative potential and promotes health and well-being	Positive effects: <ul style="list-style-type: none"> improved alertness and performance on the job, during the commute, and at home less absenteeism and presenteeism reduced errors and accidents Negative effects: <ul style="list-style-type: none"> none documented 	Positive effects: <ul style="list-style-type: none"> improved health and well-being employer-sponsored programs to diagnose and treat sleep disorders may reduce operational costs due to errors and accidents and increase employee retention Negative effects: <ul style="list-style-type: none"> none documented

Table 1. Continued

Counter-measure	Timing of use			Short-term effects	Long-term effects
	Before shift	During shift	After shift		
Wake- and sleep-promoting medications (see Appendix D5)	In consultation with a medical specialist, wake-promoting medications may be considered for individuals who experience significantly reduced alertness during the commute to work	In consultation with a medical specialist, wake-promoting medications may be considered for individuals who experience significantly reduced alertness during a shift or during the subsequent commute home	In consultation with a medical specialist, sleep-promoting medications may be considered for individuals with difficulty sleeping between work shifts	<p><i>Positive effects:</i></p> <ul style="list-style-type: none"> improved alertness and performance on the job, during the commute, and at home less absenteeism and presenteeism reduced errors and accidents <p><i>Negative effects:</i></p> <ul style="list-style-type: none"> wake-promoting medications may interfere with sleep sleep-promoting medications may result in residual sleepiness that could impair performance while at work or commuting to work wake- and sleep-promoting medications may adversely interact with other medications or alcohol melatonin, a sleep-promoting medication available over the counter in the US, may inadvertently shift the biological clock 	<p><i>Positive effects:</i></p> <ul style="list-style-type: none"> not well established <p><i>Negative effects:</i></p> <ul style="list-style-type: none"> long-term use of wake- or sleep-promoting medications may have unintended effects on sleep, mood, and health in the US, melatonin is not a regulated substance; it may contain additives with adverse health effects
Bright or blue light exposure (see Appendix D6)	Appropriately timed bright or blue light exposure may be advisable before an early morning shift or in the early morning before eastward transmeridian travel in order to help advance the biological clock	Appropriately timed bright or blue light exposure may be advisable during morning or evening hours to help advance or delay the biological clock, respectively	Appropriately timed bright or blue light exposure may be advisable after work to continue advancing or delaying the biological clock	<p><i>Positive effects:</i></p> <ul style="list-style-type: none"> short-term improvement in alertness and performance on the job or during the commute alignment of the 24-h rhythm of the biological clock to a work schedule, provided the bright or blue light exposure is appropriately timed <p><i>Negative effects:</i></p> <ul style="list-style-type: none"> if inappropriately timed, light may exacerbate circadian misalignment vision may be adversely affected by altered light conditions 	<p><i>Positive effects:</i></p> <ul style="list-style-type: none"> not well established <p><i>Negative effects:</i></p> <ul style="list-style-type: none"> shift work with long-term exposure to light at night may be associated with increased cancer risk chronic exposure to bright or blue light therapy may cause retinal damage later in life
	Appropriately timed bright or blue light exposure may be advisable before a night shift or in the evening before westward transmeridian travel in order to help delay the biological clock	Bright or blue light exposure can acutely improve alertness and may help night workers stay awake and alert during a shift	Appropriately timed bright or blue light exposure after transmeridian travel may help accelerate adjustment to a new time zone		

Table 1. Continued

Counter-measure	Timing of use			Short-term effects	Long-term effects
	Before shift	During shift	After shift		
Exercise and activity breaks (see Appendix D7)	Regular exercise is beneficial to employee health and wellness	Exercise breaks may transiently improve alertness Activity breaks may counteract adverse health consequences of prolonged sitting or poor posture Nightly exercise may facilitate adaptation of the biological clock to a night shift schedule	Exercising in the hour before bedtime may delay sleep onset	Positive effects: <ul style="list-style-type: none"> exercise may provide short-term reductions in sleepiness exercise may facilitate shifting of the biological clock Negative effects: <ul style="list-style-type: none"> exercise may reduce subjective sleepiness without improving objective performance exercise just before bedtime may interfere with sleep onset 	Positive effects: <ul style="list-style-type: none"> better health outcomes Negative effects: <ul style="list-style-type: none"> none documented
Fatigue prediction, detection and warning technologies (see Appendix D8)	Fatigue prediction, detection and warning technologies may be used before a shift to predict and help manage anticipated fatigue Fatigue prediction technologies may be used to help optimize work schedules and sleep schedules	Fatigue prediction, detection and warning technologies may be used during a shift to alert an employee or employer about elevated fatigue Fatigue prediction technologies may help guide the application of countermeasures	Fatigue prediction technologies may be used after a shift to help optimize sleep schedules Wearable technologies capable of detecting sleep may be used to monitor one's sleep debt Fatigue prediction technologies may be used to help evaluate the role of fatigue in incidents that occurred during a shift	Positive effects: <ul style="list-style-type: none"> fatigue predictions enable the development of shift schedules that minimize fatigue for some technologies, real-time feedback enables users to manage fatigue, apply countermeasures, and optimize the timing and duration of planned sleep periods fatigue warnings may help to prevent errors and accidents Negative effects: <ul style="list-style-type: none"> inaccurate, unreliable, and insufficiently validated systems may fail to detect fatigue or provide false reassurance of alertness, and may thereby increase or fail to reduce the risk of fatigue-related errors and accidents frequent false alarms desensitize users and reduce acceptance 	Positive effects: <ul style="list-style-type: none"> when used as part of a fatigue risk management system, fatigue prediction, detection and warning technologies may contribute to a cycle of continuous improvements wearable technologies enabling self-management of sleep and other health-related behaviors may contribute positively to long-term health Negative effects: <ul style="list-style-type: none"> possible legal and liability implications of data collection
Risk mitigation tools, policies, and practices (see Appendix D9)	Risk mitigation practices may be useful before a shift to prepare for work or to allocate tasks based on expected fatigue levels	Risk mitigation tools, policies, and practices may be used to mitigate risks associated with fatigue even when long shifts and fatigue cannot be avoided Risk mitigation policies may guide and facilitate the availability and use of countermeasures in the workplace	Risk mitigation policies and practices may be used after a shift to guide proper hand-off to relief workers Risk mitigation systems may include a process to continually improve fatigue risk management strategies	Positive effects: <ul style="list-style-type: none"> prevention or mitigation of fatigue-related errors and accidents Negative effects: <ul style="list-style-type: none"> risk mitigation tools and policies may be less effective when individuals using them are fatigued 	Positive effects: <ul style="list-style-type: none"> reduced operational and safety risks to individuals, organizations, and society Negative effects: <ul style="list-style-type: none"> risk mitigation tools and policies such as checklists and standard operating procedures may be less effective when individuals become complacent with routine tasks

For example, caffeine intake can decrease fatigue/sleepiness and improve alertness, performance and safety [110, 111]. However, consumption of caffeine close to bedtime, consumption of caffeine in high doses, and an individual's sensitivity to caffeine, may lead to reduced recuperative potential of sleep [112]. Similarly, naps can significantly improve alertness and

performance [113, 114]. However, naps may also result in impaired cognition for a brief period immediately after awakening [115], a phenomenon known as "sleep inertia." Thus, countermeasure use should be tailored to the context, recognizing that unintended consequences may reduce or negate effectiveness. Post-implementation monitoring of the positive and negative

effects of countermeasures implemented in a given setting is important in order to assess (and, if necessary, address) the short- and long-term benefits and costs [11]. These considerations are summarized in guiding principles 2.1–2.3 below.

Guiding principle 2.1: Countermeasures can reduce, but do not necessarily eliminate, adverse outcomes associated with shift duration.

The effectiveness of most countermeasures is influenced considerably by the specific circumstances and by inter-individual differences in their efficacy. For example, habitual caffeine users might not reap the same benefits of caffeine intake as those who only use caffeine strategically [116]. Likewise, whereas some individuals could benefit greatly from napping in the workplace, others may have difficulty napping in the suboptimal conditions of the work environment or experience profound sleep inertia [117]. As such, countermeasures are generally useful to help manage the effects of fatigue/sleepiness and related risks, but the availability of countermeasures should not, in itself, be used as a justification for making work shifts longer.

The application and effectiveness of countermeasures may be time-dependent. For example, caffeine as a fatigue countermeasure may not be helpful if used too early before a shift begins or too late during or after a shift [118], and it may interfere with sleep during the subsequent off-duty period [112]. Workers should be provided guidance on when and how to use each available countermeasure for maximal effectiveness in a given work environment. Common countermeasures, and examples of when they may be applicable, are listed in Table 1.

The countermeasures presented in Table 1 are among those most commonly used in work environments. Some of these countermeasures are supported by a large body of laboratory and field research, while others, though implemented in specific environments, remain incompletely validated. For example, many studies conducted in both laboratory and field environments delineate the optimal times and circumstances for napping [119]. By contrast, the use of exercise and activity breaks to improve alertness has limited support in the scientific literature, although these breaks may be helpful for improving health outcomes, especially for individuals working in sedentary occupations [120]. The evidence base for various countermeasures is summarized in Table 1 and in the Supplemental Material.

Educating the workforce regarding the importance of adequate sleep and strategies to reduce the short- and long-term risks associated with fatigue/sleepiness is a central component of any countermeasure program [121, 122]. Workers should be educated about the countermeasures that are available and feasible for use in their work environment and how these countermeasures should be applied. However, the extent to which individuals can be *required* to use countermeasures, such as caffeine or other stimulants, is limited [123].

Guiding principle 2.2: The development of policies regarding countermeasures and their application should be driven by an evaluation of the risks to be managed.

In some situations, a thorough evaluation may be needed to characterize the factors contributing to fatigue/sleepiness and related risks and inform the selection of the most appropriate

countermeasure(s) and implementation of any incentives to promote their use. Adopting best practices that have already been established in comparable workplaces may be expedient [124]. The operational, logistic and economic feasibility of specific countermeasures, and an assessment of whether the benefits are expected to be proportional to the costs, may determine which countermeasures are selected for implementation.

In settings that require 24-h operations, re-organizing the timing and duration of shifts can be helpful so that individual biological, behavioral and social factors are aligned with operational needs. Re-organizing working time arrangements may result in considerable return on investment, in the form of improved effectiveness, accidents avoided, reduced absenteeism and presenteeism, and greater retention [23, 51]. Another option that may prove cost-effective is the use of caffeine. For example, an evidence-based guideline for emergency medical services (EMS) recommends wide availability of caffeine in EMS operations [111].

Guiding principle 2.3: Monitoring the effects of countermeasures is important to determine their effectiveness, identify any unintended consequences, and evaluate opportunities for improvement.

Post-implementation monitoring of the effects, both positive and negative, of countermeasure implementation will inform whether any modifications are needed to better manage shift duration-related risks [11, 125]. Monitoring could involve the assessment of a variety of outcomes, including objective as well as self-report data from workers, productivity-related metrics, and fatigue/sleepiness-related incident reports and absenteeism rates [126].

For example, the introduction of a dedicated nap room into a work environment has the potential to reduce fatigue/sleepiness, but practical aspects or work culture may serve as barriers to the use of the nap room [127], or sleep inertia may reduce the ability to perform after a nap [128]. Post-implementation surveillance to determine when and how long employees are napping, coupled with objective performance indicators, may confirm that the nap room is working as intended, or that additional countermeasures are needed to address unintentional consequences [129]. In this example, a formal hand-off protocol may be needed to facilitate the re-entry of an individual onto the work floor after a nap to address potential sleep inertia. Post-implementation surveillance assesses whether countermeasures are being used, whether they are beneficial, and what additional efforts may be needed to make them most effective [11].

Decision-Making About Shift Duration

Multiple, potentially competing factors may play a role in decision-making about shift duration. To weigh such factors appropriately, the risks associated with shift duration and the countermeasures used to reduce these risks must be considered relative to a *risk tolerance level*—that is, the potential consequences that stakeholders are willing to accept in the context of what needs to be accomplished during the work shift and how important it may be that the work gets done [130]. For example, the risk tolerance level for cross-continental organ transplant air

transportation may be relatively high, so that stakeholders may be accepting of long shifts to make these kinds of life-saving operations possible, recognizing that they occur infrequently and are unlikely to incur cumulative risks from back-to-back operations.

The risks associated with long work shifts may not fall on the same individuals as the benefits [11]. As such, involving a sufficiently broad spectrum of potential stakeholders is important in the decision-making process regarding what shift durations, and what risks, are acceptable. Relevant stakeholders include but are not limited to employees, managers, unions, regulators, safety officers, medical directors, shareholders, communities, and/or their representatives.

Guiding principle 3.1: Determining maximum shift duration requires stakeholders to balance risk factors, countermeasures, and potentially competing goals.

Determining appropriate shift durations involves a potentially complex tradeoff between the competing goals of stakeholders or their representatives. For example, employers need to balance profitability and operational outcomes with the safety and health of employees or client and community expectations. Employees may need to balance their income and the organizational expectations they face against time spent with personal activities. Regulators may need to balance the competing demands of businesses and employees against the interests of the public. The community often has to balance their expectations for the availability of around-the-clock services against the costs associated with providing those services.

These tradeoffs are further complicated by competing demands related to extended shift durations. For example, employers may adopt a policy of extended work hours to address the occasional need to deliver urgent or emergency services, even though a different policy could be a better choice—for example, a policy that sets more limited work hours and allows for occasional exceptions in which the risk of cumulative sleep loss is mitigated with protected post-duty recovery periods. Short-term financial and operational considerations must be weighed against long-term consequences for worker health and well-being or costs borne by the broader community (e.g. increased accident rates, need for extended childcare services, demands on the health care system). Ensuring that all stakeholders understand and acknowledge these tradeoffs is critical to designing effective policies about appropriate shift durations.

Guiding principle 3.2: The decision-making process about shift duration should be fully informed, transparent, and based on scientific evidence.

Ideally, all stakeholders should participate responsibly in the decision-making process regarding the appropriate duration of shifts. The decision-making process requires stakeholders to consider all of the operational consequences, as well as identify and manage any associated risks. In determining appropriate shift durations and requirements for countermeasures to reduce risks, organizations should develop a stakeholder input process that clearly identifies the potential risks, costs and benefits to all stakeholders. The risks should be evaluated both

on average (typical risks) and in the extreme (potential for catastrophic outcomes).

Decisions about shift duration are often made without a comprehensive assessment of the scientific evidence that can inform the decision-making process. All decision-makers should therefore be aware of the potential implications of their decisions and the often-competing nature of priorities and outcomes. Regulators have a key role in providing balanced guidance materials that identify likely costs and benefits and assist non-expert stakeholders in interpreting and applying the relevant scientific evidence.

The quality, relevance and generalizability of scientific evidence supporting decision-making about shift duration is highly variable [51]. However, a lack of compelling scientific evidence for a given decision-making factor (e.g. that certain work practices cause fatigue, or that certain countermeasures are effective) should not be seen as evidence against that factor. Insufficient scientific evidence could be due to logistical or financial barriers to conducting the research, not because the factor is irrelevant or unimportant, and testimony from experts familiar with the operation may be required. The limits of the available knowledge base, and the extent to which that knowledge base generalizes to the organization or industry in question, should be discussed explicitly. Any uncertainty in supporting evidence should reinforce the necessity of post-implementation surveillance programs (see guiding principle 3.5). Such programs can yield information about the efficacy of specific practices, which should be publicized whenever possible so that the knowledge base is expanded for future efforts.

Guiding principle 3.3: The decision-making process about shift duration should faithfully represent the interests of all stakeholders and respect the legitimacy of these interests.

Conflicts of interest can often arise between stakeholders and their representatives. Decision-makers who act on behalf of others should be expected to demonstrate that they are promoting the declared interests of those they represent in an accurate manner. To ensure this, those whose lives and livelihoods would be directly impacted by changes to shift duration should be permitted and encouraged to participate in the decision-making process.

Decision-makers will often use dissimilar criteria or values to determine the most appropriate shift durations. Sometimes these criteria involve factors outside the workplace. Acknowledging concerns about the impact of work hours on non-work-related factors, and treating such concerns as legitimate, is critical. Though doing so may not change the decision, such acknowledgment enables organizations to predict and address post-implementation issues before they lead to significant negative outcomes, such as increased absenteeism or the loss of valuable employees.

The impact of changes in shift duration can manifest outside the workplace. For example, extending a shift from 8 to 12 h might impose difficulty in finding childcare. Inevitably, decisions to change shift duration will not be universally welcomed. Organizations should acknowledge any inconvenience caused and take reasonable steps to minimize the inconvenience, where possible, or provide reasonable time to adjust to altered working time arrangements.

Guiding principle 3.4: Deliberations, policies, and documentation regarding shift duration should be supported by an organization's safety management architecture.

In many organizations and industries, policy regarding shift duration has been considered a matter to be addressed by labor law or human resource departments, rather than a workplace safety and health issue. However, shift duration is foremost a safety and health issue with legal implications, and policies and procedures pertaining to shift duration are best embedded within organizational risk and safety management systems [121]. Many industries have pre-existing policy frameworks from which to draw, such as workplace health and safety policies, Safety Management System policies, or (Fatigue) Risk Management policies; see [Appendix B](#). In most cases, employers and employees and their representatives should assign primacy to safety and health implications of shift duration over social and financial ones.

Guiding principle 3.5: Changes to rules and policies on shift duration should be monitored and evaluated, and corrective action should be taken in the event of unintended outcomes.

Emerging evidence indicates that changes in working time arrangements can produce unintended and paradoxical outcomes. The reasons for this often reflect unique aspects of the workplace, workforce or work tasks. Workplaces are complex environments whose responses to changes in the working time arrangement can be hard to predict. As a consequence, following changes in shift duration, organizations should monitor and respond to leading indicators of potential problems and both positive and negative outcomes to ensure the effectiveness of shift duration policies [11].

Monitoring systems should identify, report, quantify and manage existing and emerging risks [121]. Recommendations for the development of such systems are provided in [Appendix C](#). Larger organizations should seek independent, third-party input in the evaluation of their policies and procedures for managing the risks associated with shift duration. The need for and timing of such input should be based on defined criteria, such as the typical level of operational risk, or the emergence of new or changing data that would benefit from this type of expertise.

Conclusion

Maximum work shift durations have historically been based on a balance between workplace productivity and physical fatigue-related risks, with insufficient consideration of the impact on mental fatigue and associated risks regarding performance, safety, and health. Based on the guiding principles with respect to shift duration-related risks as described in section "Risk Factors Associated with Shift Duration" and mitigations provided by countermeasures as described in section "Countermeasures for Risks Associated with Shift Duration," policies regarding shift duration should be context-specific and based on a tradeoff analysis that incorporates a comprehensive assessment of needs and risks as described in section "Decision-Making About Shift Duration." A variety of factors may increase or decrease shift

duration-related risks, and conditions may exist that impact acceptable solutions, such as emergency operational needs, economic acceptability, and workplace, political or legal culture. Ultimately, solutions should be designed such that compliance with their content is congruent with desired outcomes; otherwise, not only would such approaches be ineffective, but individuals and organizations may be less willing to adhere to them, and remain vulnerable to harmful downstream risks.

A key question in determining shift duration is whether and when the risks of continuing to work become greater than the risks of ceasing to work [11]. The relevant risks may occur along a spectrum of severity or acceptability, and may be multi-dimensional, impacting various functional domains and diverse individuals or groups of individuals [8]. The assessment of these risks, therefore, includes consideration of their impact on the various stakeholders; indeed, those who may be most impacted may differ from those who reap the greatest benefits of a particular shift duration policy.[11] A choice of whether to accept the risks or intervene to reduce the risks is then required. The guiding principles provided in this document are meant to help devise tailored solutions to address these issues.

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Appendix A. Biological Processes of Sleep/Wake Regulation

Mental fatigue, as defined earlier in this paper, is influenced strongly by sleepiness, and thereby by time of day and by the durations of wakefulness and prior sleep. This relationship is governed by two primary biological processes: the “circadian” wake drive and the “homeostatic” sleep drive [131–133]. During the day, the circadian process produces rising pressure for

wakefulness, which counteracts sleepiness. During the night, the circadian process withdraws this wake pressure, which promotes sleepiness and tendency to fall asleep. Simultaneously, during periods of wakefulness, the homeostatic process builds up pressure for sleep, which promotes sleepiness. During sleep periods, homeostatic pressure for sleep dissipates; the longer the sleep period, the less the remaining homeostatic sleep drive. Awakening from sleep occurs naturally when the remaining homeostatic sleep drive is overcome by the circadian wake drive. At any given time during wakefulness, sleepiness—and thereby mental fatigue as defined in this paper—is thus influenced by the interplay between the two processes, as illustrated in [Figure A1](#).

Because the circadian process is a function of time of day, while the homeostatic process is a function of time awake and time asleep, the interplay between the two processes depends critically on the timing of periods of wakefulness and sleep. [Figure A1](#) illustrates this for a healthy young adult in a day work scenario with daytime wakefulness and nighttime sleep (left panels), and in a night work scenario with nighttime wakefulness and daytime sleep (right panels). In the day work schedule, the interplay between the circadian and homeostatic processes maintains a stable, low level of sleepiness during most of the day, followed by a rapidly rising level of sleepiness in the late evening leading to the initiation of sleep. Furthermore, during nighttime sleep, the interplay between the two processes produces a consolidated sleep period. If the sleep period is not long enough, dissipation of the homeostatic pressure for sleep may be insufficient, and use of an alarm clock may be needed to wake up in time for work or other responsibilities.

By contrast, in a night work schedule, the interplay between the circadian and homeostatic processes produces a steady increase in sleepiness through most of the night. Furthermore, the rising circadian wake drive during daytime sleep causes early awakening and incomplete dissipation of the homeostatic pressure for sleep. High circadian wake drive during the late afternoon and early evening (the so-called “forbidden zone for sleep” [134] or “wake maintenance zone” [135]) makes it difficult to obtain additional sleep during the afternoon. Thus, compared to a day work scenario, a night work scenario tends to produce sustained sleep loss and dynamically changing, higher levels of sleepiness [13].

Given this biological regulation of sleepiness and its impact on mental fatigue, a prescriptive limit on work hours would not, by itself, prevent high fatigue levels during a night work schedule. (In fact, a prescriptive limit on work hours could inadvertently place the commute home at the time of greatest sleepiness, just before the rising circadian wake drive would partially reduce sleepiness again and mitigate fatigue [11].)

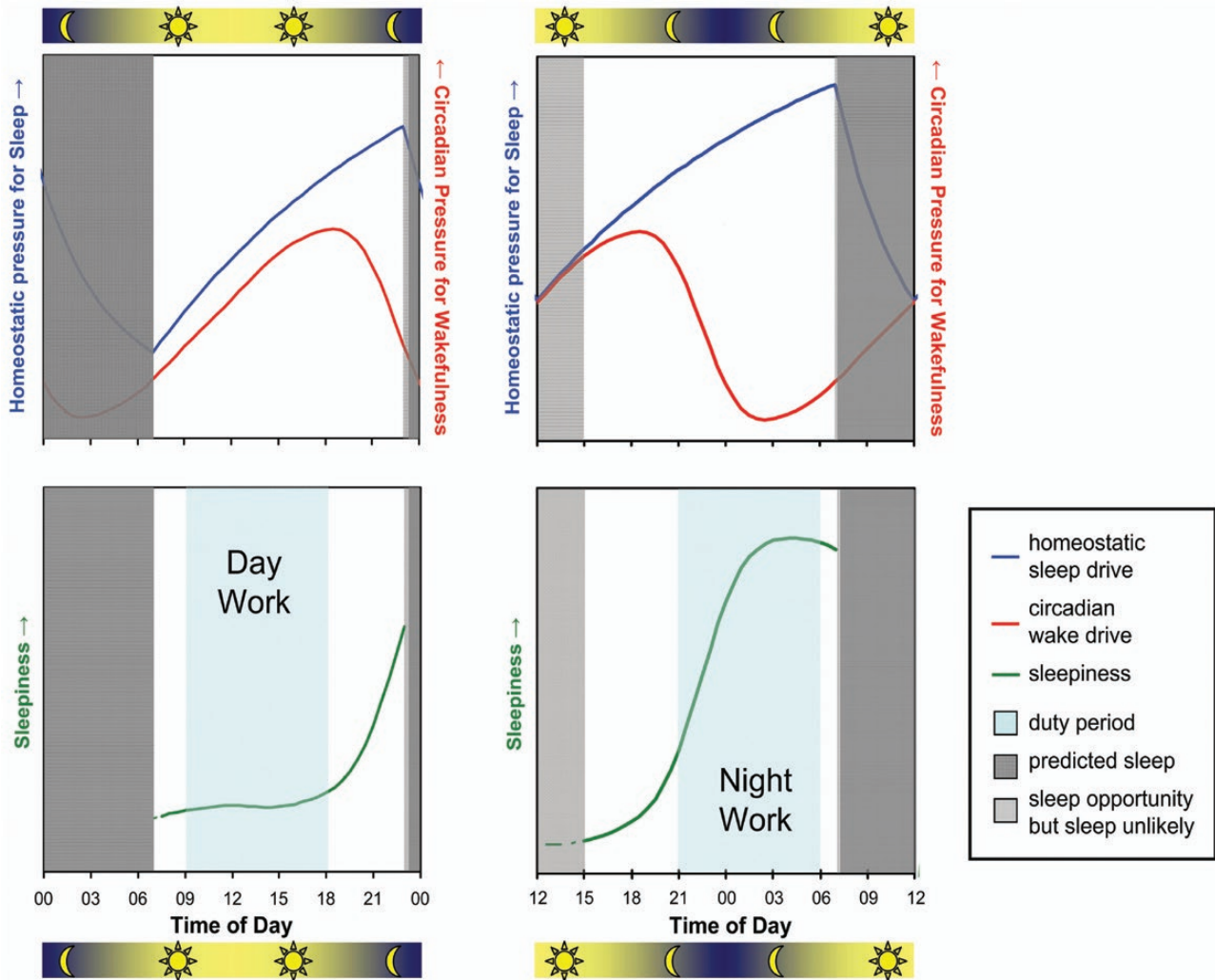


Figure A1. Regulation of sleepiness by two biological processes. A circadian process (red) produces a rising pressure for wakefulness, which counteracts fatigue, during the day; and a withdrawal of that pressure for wakefulness, thereby promoting sleepiness, during the night. Simultaneously, a homeostatic process (blue) builds up a pressure for sleep, thereby promoting sleepiness, during periods of wakefulness; and dissipated that pressure for sleep (dark gray), thereby providing recovery, during periods of sleep (top panels) [131]. The combined effect of the circadian and homeostatic processes on sleepiness may be calculated as the *net difference* between the homeostatic pressure for sleep and the circadian pressure for wakefulness (bottom panels, green) [132], as illustrated here for a scenario with a daytime duty period (light blue) and an 8-h nighttime sleep opportunity (left panels) and for a scenario with a nighttime duty period (light blue) with an 8-h daytime sleep opportunity (right panels). Note that in the day work scenario, the sleep opportunity is ended (e.g. through use of an alarm clock) somewhat prematurely, as there is still some homeostatic pressure for sleep left to be dissipated (top left). In the night work scenario, however, sleep is curtailed much more, with the rising circadian wake pressure causing awakening during daytime sleep well before the end of the sleep opportunity. The early awakening leaves a higher level of homeostatic sleep pressure at the end of the shortened sleep period (dark gray) and causes a portion of time available for sleep in this scenario (light gray) to remain unutilized (top right). The combined effect of the two processes—sleepiness calculated as the net difference between the homeostatic pressure for sleep and the circadian pressure for wakefulness—is that sleepiness is low and stable throughout the duty period in the daytime duty scenario (bottom left), whereas sleepiness increases and peaks toward the end of the duty period in the nighttime duty scenario (bottom right). Note that the transient cognitive impairment immediately after awakening known as sleep inertia [115] is not depicted in this figure.

Appendix B. Example Risk and Safety Management Policy Frameworks

Shift duration is a safety and health issue with legal implications, and policies and procedures pertaining to shift duration are best embedded within organizational risk and safety management systems [121]. Many industries have pre-existing policy frameworks from which to draw, such as workplace health and safety policies, Safety Management System (SMS) policies, or Fatigue Risk Management (FRM) policies. Here we provide a few links to example frameworks and free resources (shared with permission), which may serve as a starting point for organizations to establish their own policies:

- The “Fatigue Risk Management Toolkit for Residents, Leaders, and Policy Makers in Canadian Postgraduate Medical Education” document contains practical tools and an implementation guide for managing fatigue in Canadian medical education. In large part it readily applies to U.S. medical education settings. It can be downloaded from: <http://www.residentfatigue.ca/mssites/frm/PDF/Fatigue-Risk-Management-Toolkit-WEBS.pdf> (last accessed on March 30, 2021).
- The “FRM Standard Operating Procedure for Utilities” document provides a straightforward but comprehensive standard operating procedure for a fatigue risk management system (FRMS) currently used in Australia. It may be adapted

for U.S. operations and can be downloaded from: <https://www.sleepresearchsociety.org/wp-content/uploads/2021/03/FRM-Standard-Operating-Procedure-for-Utilities.pdf> (last accessed on March 30, 2021).

- The Fatigue Risk Management Systems Implementation Guide for Operators, 1st edition [6] developed by the International Air Transport Association (IATA), the International Civil Aviation Organization (ICAO), and the International Federation of Airline Pilots' Associations (IFALPA) is widely seen as a model for FRMS in larger operations. It can be downloaded from: <https://www.icao.int/safety/fatiguemanagement/FRMS%20Tools/FRMS%20Implementation%20Guide%20for%20Operators%20July%202011.pdf> (last accessed on March 30, 2021).
- The 2018 Fatigue Risk Management Guidelines for Emergency Medical Services Implementation Guidebook helps EMS administrators with the implementation of rigorously developed, evidence-based guidelines [52] for fatigue risk management in EMS, with condensed summaries of recommendations and sample policy statements that may be tailored to the needs of local agencies. It can be downloaded from: <https://nasemso.org/wp-content/uploads/Fatigue-Guidebook-FINAL-2018Oct.pdf> (last accessed on March 30, 2021).

In addition, the "Fatigue at Work Employer Toolkit" developed by the National Safety Council (NSC) contains educational materials for human resources personnel, supervisors, and employees pertaining to fatigue-related safety risks. It can be downloaded from: <https://safety.nsc.org/fatigue-risk-management-toolkit> (last accessed on March 30, 2021).

Appendix C. Recommendations for the Development of Systems to Monitor the Outcomes of Changes in Shift Duration

After making changes in shift duration, organizations should monitor and respond to leading indicators of potential problems and both positive and negative outcomes to ensure the effectiveness of their shift duration policies. Monitoring systems should identify, report, quantify and manage existing and emerging risks. For the development of such systems, the following recommendations deserve consideration:

- (1) The degree (and likely cost) of monitoring should be proportional to the anticipated risk level. Where the risk level is low, monitoring may be relatively minimal. Where the risk level is high, however, monitoring should be more comprehensive, evidence-based and, in larger operations, bolstered by third-party oversight.
- (2) Monitoring systems should identify and report key performance indicators. These indicators should enable the organization to demonstrate evidence for the following.
 - (a) There is appropriate knowledge of relevant policies, including personal and organizational roles and responsibilities in identifying, reporting, quantifying and mitigating the risks associated with extended shifts.
 - (b) There is appropriate training and education of staff in how to identify, report, quantify and manage the risks associated with extended shifts.
 - (c) Methodologies used for measuring, reporting and mitigating risks are evidence-based, subject to regular

evaluation and, where appropriate, modified in light of local experience and/or relevant or emerging scientific evidence. These could include, and are not limited to, measures of:

- o planned and actual working time arrangements for all at-risk employees, including planned and unplanned overtime, on-call work, secondary employment, or other activities likely to interfere with sleep;
 - o sleep-wake behavior of individual employees, as part of a shared-responsibility framework in which employer and employees have joint responsibility for ensuring adequate sleep;
 - o fatigue/sleepiness-related changes in behavior or task performance;
 - o self-report measures of fatigue, sleepiness, alertness, or fitness-for-duty;
 - o the efficacy and utilization rates of *in situ* countermeasures at the organizational level.
- (3) Based on data obtained in (2), organizations should respond appropriately to opportunities to apply corrective actions that will reduce risks associated with shift duration.
 - (4) Monitoring systems should be cost-effective, so that the costs of implementation, or of the application of corrective actions, does not exceed the likely benefits. This guidance should, however, not be interpreted as advice to minimize resources dedicated to monitoring.
 - (5) Organizations should implement a system that will enable them to identify and respond to any meaningful relationships between shift duration and risk outcomes including, but not limited to, productivity, performance, safety, health, and community and environmental consequences.

Appendix D. Background Information on Countermeasures for Risks Associated with Shift Duration

This Appendix provides background information and references that pertain to selected countermeasures for risks associated with shift duration as shown in Table 1. Implementation of these countermeasures can be complex, and consultation with an expert is generally recommended.

D1. Scheduling Improvements for Shift Work and Extended Shift Operations

Thoughtful and data-driven design of working time arrangements can contribute to risk mitigation by maximizing and protecting sleep opportunities, aligning work schedules with the circadian rhythm of the biological clock, and/or increasing time for recovery after extended duties or multiple shifts. While the primary focus of this paper is on shift duration, the timing of shift starts and ends, and other aspects of the working time arrangements are also important to consider in this regard [136, 137]. Scientific evidence pertaining to these issues is limited, and conclusive studies of scheduling improvements are largely lacking due to a wide range of possible confounds [138]. Nonetheless, the following guidelines provide some insight into what kinds of scheduling practices affect performance, safety, and health risks and therefore present potential opportunities for improvement.

- Shift systems with backward rotation, in which the start times of consecutive shifts is advancing (i.e. the next block of shift starts at an earlier time of day than the current block), are generally less well tolerated than shift systems with forward rotation or fixed shift times [81]. The speed of rotation (i.e. how many shifts in a block with the same start time) also plays a role in rotating shift systems, but the evidence on its effects is mixed [139].
- Both night shifts and early morning starts curtail nighttime sleep opportunities, which increases risk levels relative to late morning and afternoon/evening shifts [77, 140].
- Shift durations beyond 12 h in duration tend to be associated with increased risk levels [80, 140]. Shift durations of 24 h or more without protected opportunities to nap while on duty are not recommended [51]. Evidence is mixed, however, on 12-h shifts compared to 8-h shifts [51, 141].
- Risk levels tend to accumulate across consecutive shifts without days off [142, 143].
- Double (i.e. back-to-back) shifts and quick returns, overtime, and second jobs increase risk levels [22, 144, 145].
- Irregular and unpredictable work hours and on-call duty schedules are often perceived as stressors and may also interfere with the ability to obtain adequate sleep, thereby increasing risk levels [9, 146].
- Whereas the impact of workload (or task load) is not well established [147, 148], high workload may interfere with control over the pacing of work tasks and restrict time for rest breaks, which may increase risk levels.

D2. Napping

Taking a nap—a relatively short sleep period that may be (loosely) defined as less than half the duration of an individual's typical nocturnal sleep length—is an effective way to supplement the daily amount of sleep and a powerful countermeasure to sleepiness and fatigue [149–153]. Naps as short as 15 min and as long as several hours can be effective, whether before work (pre-emptive or prophylactic naps), during work (on-the-job or strategic naps), or after work (catch-up naps) [112, 154–156]. Naps may facilitate adaptation to a shift work schedule and ease the return to daytime activity [157, 158], and may offer cardiovascular health benefits [159, 160]. Split sleep schedules, in which a person takes a nap after a work shift and another nap before the next shift, have been associated with increased sleepiness [161], but few differences in performance relative to a consolidated post-shift sleep bout [162, 163]. For on-the-job napping to be implemented successfully as a countermeasure strategy, it is important that it be sanctioned [164] and that there is access to a safe and quiet place to rest while on break [109, 127].

Importantly, napping may produce post-nap sleep inertia, a transient feeling of grogginess and impaired performance immediately upon awakening [115, 165]. Sleep inertia can be particularly problematic in on-call settings [146] and may require a worker to delay the return to work for up to about 30 min after waking [166, 167]. Sleep inertia may be less intense after shorter (approximately 10–30 min) naps, but scientific evidence on this matter is inconclusive [168]. Caffeine consumed just prior to a nap appears to be an effective countermeasure to performance impairment due to sleep inertia immediately after the nap [129] (see Appendix D3).

D3. Caffeine Use

There is abundant evidence that caffeine reduces sleepiness and fatigue and mitigates deficits in cognitive performance [116, 169]. When caffeine is used in conjunction with a nap, it may also reduce the time to overcome post-nap sleep inertia [170–173]. Caffeine is widely available and found in many drinks and foods, either naturally occurring or as an additive; furthermore, caffeine can be obtained in the form of chewing gum and various over-the-counter medications. Available evidence suggests that moderate use of caffeine is compatible with a healthy lifestyle [174].

The pharmacodynamics of caffeine are poorly understood, and large inter-individual differences in caffeine sensitivity, effectiveness, habituation, and tolerance exist [175–177]. This limits the ability to provide tailored advice regarding dosing of caffeine to mitigate fatigue – although given the widespread presence of caffeine in foods and drinks, precise dosing could be difficult in practice regardless. Even so, the preponderance of scientific evidence indicates that caffeine is an effective fatigue countermeasure, and access to caffeine as part of a comprehensive fatigue risk management program is recommended [111].

Caffeine present in the bloodstream just before bedtime may delay sleep onset and reduce the quality and quantity of subsequent sleep, although individuals differ considerably in their sensitivity to these effects [178]. Sustained use of high-dose caffeine can cause additional undesirable effects, including anxiety, tremor, arrhythmias, insomnia, dehydration, and withdrawal headaches [179, 180]. For healthy adults, caffeine consumption up to about 400 mg per day (300 mg per day in pregnant women) is generally considered safe [181]; however, the decision to use caffeine and the amount and frequency of use should be based on individual assessment of benefits versus undesirable side effects.

D4. Sleep Hygiene and Treatment of Sleep Disorders

Sleep disturbances that are not necessarily related to the work environment contribute to work-related errors and injuries [182]. Sleep hygiene, which refers to a set of behavioral and environmental recommendations intended to promote good sleep [183], can help to obtain adequate duration of quality sleep. The recommended amount of sleep for the average adult is 7 h per night or more [105, 106]. Achieving this on a regular basis provides some degree of resilience against the adverse cognitive effects of subsequent sleep loss [184, 185].

Sleep hygiene environmental recommendations, which pertain to personal sleep spaces as well as any workplace sleep facilities, include ensuring a comfortable, appropriately sized bed; minimal light exposure and noise; comfortable temperature and humidity; and no sleep interruptions (unless there is an emergency) [186, 187]. Sleep hygiene behavioral recommendations found in the literature, which are primarily focused on the habitual sleeping environment, include maintaining regular bed and wake times; avoiding daytime naps; avoiding bright light exposure during the 2–3 h prior to sleep; avoiding large meals or alcohol consumption for at least 2 h prior to bedtime; avoiding strenuous exercise immediately before bedtime; and avoiding caffeine, nicotine, and other stimulants for at least 6 h before bedtime [187, 188].

In operational settings, some or all of the behavioral recommendations may not be feasible or practical to implement (e.g. because irregular work schedules may interfere with maintaining regular bed and wake time) and may actually be at odds with effective fatigue risk management (e.g. because taking a daytime nap may be needed to mitigate fatigue). That is, some of the behavioral recommendations could be counterproductive for getting enough sleep or ensuring optimal performance and safety (especially in shift work settings). Also, although they are worthy sleep health recommendations in their own right, evidence of their effectiveness with regard to workplace performance, safety and health is limited [188]. The behavioral recommendations should therefore not be seen as advice against pursuing catch-up sleep or naps, or using bright light or caffeine prior to bedtime, when doing so would be the better choice for safety.

Sleep disorders (e.g. obstructive sleep apnea, insomnia), medical conditions (e.g. diabetes mellitus, gastroesophageal reflux disease, back pain), and psychiatric disorders (e.g. depression, post-traumatic stress disorder) can transiently or chronically reduce the quality and quantity of sleep [189]. For affected workers this can result in poor sleep quality, insufficient sleep, or excessive sleepiness, which can then negatively affect work performance. Additionally, some medications (e.g. hypnotics, antidepressants) incur side-effects that contribute to increased risk of fatigue during work hours, either through direct effects on sleepiness, or indirectly by worsening sleep quality or decreasing sleep duration [190]. Workplace education regarding sleep disorders, treatment, and implications for safety and well-being has been found to reduce risk of occupational injuries [191]. Furthermore, an employer-supported sleep disorder (obstructive sleep apnea) treatment program in the U.S. trucking industry has been shown to yield significant benefits in terms of crash risk, driver retention, and medical insurance costs [192, 193].

D5. Wake- and Sleep-Promoting Medications

Wake-promoting (stimulant) and sleep-promoting (hypnotic) medications should be used in consultation with and under supervision of a medical provider with expertise in management of sleep/wake disturbance associated with non-traditional work hours. A discussion of their pharmacological and clinical specifications is beyond the scope of this paper but can be found in the literature [194, 195]. The advantages and disadvantages of wake- and sleep-promoting medications and the legal and ethical considerations for their use in operational settings have also been discussed in the literature [123, 196]. Certain occupations have regulations or policies that prohibit the use of some or all of these medications.

Use of wake-promoting medications may interfere with the ability to obtain adequate sleep after bedtime [197]. Use of sleep-promoting medications may result in next-day residual sedation, which could impair performance while at work or commuting to work [198], although caffeine intake may be helpful to mitigate this effect [199]. Long-term use of wake- or sleep-promoting medications may have unintended effects on sleep, mood, and health [195, 200]. Interactions with other medications or with alcohol [201] may increase the risk of side effects from wake- or

sleep promoting medications. Alcohol, which some individuals use as a sleep aid, may degrade sleep quality, exacerbate sleep apnea, and cause next-day sleepiness [202].

Melatonin, which in the United States is available over the counter as a dietary supplement, is usually marketed and used as a sleep aid. However, the primary effect of melatonin—a hormone that is also naturally produced by the pineal gland during the evening and night—is that it can shift the timing of the biological clock [203]. As such, melatonin may be used to help realign sleep-wake timing and facilitate daytime sleep for night shift workers [204] or to help overcome jet lag after travel across time zones [205]. Optimizing the timing of melatonin administration is critical to achieving the desired effect, with morning administration leading to delays of the biological clock (shifting sleep later) and evening administration leading to advances of the biological clock (shifting sleep earlier) [206]. This makes achieving optimal effectiveness complicated in practice, and mistimed melatonin administration may even result in the opposite effect of what is desired. Melatonin use is generally considered safe and side effects are minimal [207], but it is not regulated in the United States and may contain additives with adverse health effects. As with other sleep-promoting medications, a medical provider with expertise in management of sleep/wake disturbance associated with non-traditional work hours should be consulted if melatonin is considered as a potential aid for sleep difficulties in the context of working time arrangements.

D6. Bright or Blue Light Exposure

Light has the potential to shift the biological clock, and it also affects alertness [208]. Morning light exposure causes the biological clock to advance (shift earlier), and evening light exposure causes the clock to delay (shift later) [209, 210]. The magnitude of these effects depends on the duration, brightness, and color of light exposure. The brighter the light and the longer the exposure, the greater the shifting [211, 212], and light that is blue or blue-enriched is particularly effective for shifting the biological clock [213]. Based on these principles, manipulation of light exposure can be used to shift the biological clock by some desired amount of time, for example to facilitate adaptation to a shift work schedule [214]. Optimizing the timing of light exposure is critical to achieving the desired effect [208].

The biological clock tends to shift no more than a few hours per day. This approach to shift work adaptation would therefore only work well for fixed or slowly rotating shift schedules, in which shift start or end times are expected to occur at approximately the same time for several consecutive days. Even then, additional measures may be required, such as wearing dark goggles or using technological solutions to reduce bright or blue light exposure at certain times [215], making the desired effect difficult to achieve [216]. Strategies for mitigating risks in shift workers that rely on minimization of extended wakefulness and sleep loss, rather than shifting the biological clock, may be more effective in practice.

Light exposure has an acute alerting effect [217]. To some extent the magnitude of this effect depends on the brightness level of the light [218], and light that is blue or blue-enriched is particularly effective for promoting alertness [219]. Little is known about how long the alerting effect of light exposure

lasts after the exposure has ended [220]. That said, use of blue-enriched white light in the workplace has been reported to improve alertness, performance, and sleep quality [221]. The acute alerting effect of light, however, cannot be separated from its effects on the biological clock. Especially in shift work settings, therefore, individuals exposed to bright or blue light to improve alertness may also experience a shift of the biological clock, which may or may not be problematic depending on the situation. Furthermore, inappropriate light exposure has the potential to adversely affect sleep. In many situations, therefore, light may not be a suitable countermeasure for risks associated with shift duration.

Exposure to light at night associated with shift work has been found to increase the risk of cancer [222–224]. Additionally, chronic exposure to bright or blue light therapy has been linked to retinal damage later in life [225, 226]. This finding awaits corroboration with additional clinical studies.

D7. Exercise and Activity Breaks

In addition to the well-known benefits of physical activity from exercise and activity breaks with regard to skeletomuscular and overall health and wellness, physical activity has some potential to improve sleep [227, 228]. However, exercise less than 1 h before bedtime may delay sleep onset [229]. Exercise also has the potential to shift the biological clock, with morning exercise facilitating advances and evening exercise facilitating delays of the biological clock [230]. In the laboratory, nightly bouts of exercise have been found to promote adjustment of the biological clock to a night shift schedule [231].

During sleep deprivation, physical activity may produce a modest short-term reduction in subjective sleepiness, but there may not be any concomitant improvement in cognitive performance [232]. A review of continuous exercise at active workstations found minimal evidence for increased workplace performance or productivity [233]. The extent to which exercise can be used effectively as a fatigue or risk countermeasure in operational settings remains to be investigated.

D8. Fatigue Prediction, Detection and Warning Technologies

Technologies available to help manage risks from fatigue can be broadly categorized as biomathematical models of fatigue [234], tools for monitoring sleep and sleep debt [235], tools for detecting and warning about fatigue [236], and fitness-for-duty tests [237]. Biomathematical models of fatigue make use of equations describing the regulation of sleep and wakefulness and the biological clock to provide predictions of sleepiness or performance impairment for a (hypothetical) average individual, based on a given sleep schedule or work schedule [238, 239]. Use of these models is commonplace before, during and after duty periods in commercial and military aviation [240, 241], where shift scheduling is typically tightly managed. However, they are deemed to be of more limited utility in settings where shift scheduling is on demand or otherwise less strictly under operational control [242].

Tools for monitoring sleep have become widely available in the consumer market over the last decade. Frequently integrated with physical activity and health monitoring systems, they

usually consist of wearable sensors coupled with a smartphone-based software application [243]. Such tools do not usually meet professionally accepted criteria for sleep assessment [244], but have been found helpful in allowing individuals to monitor and potentially improve their sleep [245] or potentially seek medical evaluation. Tools for monitoring sleep may also serve to determine a person's sleep schedule for use with a biomathematical model of fatigue in order to predict impending safety risks [246]. A significant challenge with wearable technologies is user acceptability; people often do not tolerate wearing additional devices, especially if they are uncomfortable or obtrusive, interfere with work, or do not also fulfill other useful functions [247].

Tools for detecting and warning about fatigue, commonly referred to as fatigue (or drowsiness) detection and warning systems, are manifold and diverse. Technologies for fatigue detection aim generally to measure fatigue continuously from unobtrusively observable signals that correlate with fatigue, such as various ocular measures, sleepiness-related variables derived from the electroencephalogram (EEG), indices of heart rate variability, changes in speech and voice, or facial expressions. A diversity of modalities for providing fatigue warnings have been implemented, including visual, auditory, and haptic alerts as well as warning messages transmitted to third parties for possible intervention. In cars and trucks, fatigue and error detection systems may activate driver assist technologies to help avoid accidents [69].

In contrast to fatigue detection and warning systems, tests for fitness-for-duty (or readiness-to-perform) typically provide snapshot measures of fatigue and often require an individual's active involvement such as performing a reaction time task [248] or taking a balance test [249]. While fatigue testing for fitness-for-duty provides an instant, objective estimate of a person's level of fatigue, such testing does not track subsequent changes in fatigue over time unless the test is conducted repeatedly (although such changes could conceivably be predicted using a biomathematical model). Most fitness-for-duty tests are not specific for fatigue; other sources of impairment (e.g. distraction, alcohol intoxication) produce similar test results. For fitness-for-duty tests that rely on user response to assess fatigue, variations in motivation and effort may also influence test results.

Fatigue prediction, detection and warning technologies that have been shown to be both sensitive and specific to relevant levels of fatigue are rare. However, both of these accuracy attributes are important. Technologies need to be sensitive enough to detect or predict levels of fatigue that compromise performance and safety, as failures to identify these could have critical, even fatal consequences. At the same time, technologies need to be specific enough not to inadvertently trigger alerts when fatigue levels are low, as too many false alarms will quickly desensitize the user. Many of the currently available technologies are proprietary, and the extent to which they have been subjected to independent research is often limited. For most of these technologies, publicly accessible data on accuracy, reliability, and validity are limited or unavailable.

Collection of objective data in operational settings may have important implications for privacy and could carry liability for employers and employees. For example, following an accident in which fatigue is suspected to be a main contributor, sleep monitoring data may be subpoenaed to determine the amount of sleep obtained prior to the accident. This potential issue notwithstanding, when used as part of a comprehensive fatigue

risk management system, fatigue prediction, detection and warning technologies may contribute to a worthwhile, data-driven process of continuous improvements in risk mitigation (see Appendix D9).

D9. Risk Mitigation Tools, Policies, and Practices

Even though shift duration and its attendant fatigue may be the source of risks to performance, safety, and health, countermeasures do not necessarily have to address the source of these risks to mitigate the risks themselves [70]. There are many possibilities for “fatigue proofing” that mitigate or avoid risks through other means [250], such as use of task checklists and standard operating procedures (e.g. for end-of-shift hand-offs) [5], team work strategies [29], extra staffing [144], scheduled rest breaks [81], providing safe transportation options after work shifts [251], engineering solutions (e.g. safety valves in factories, rumble strips on the road, automation in the operation of machines) [5], and implementation of safety policies, procedures, and management systems [23] (see also Appendix B). Furthermore, an educated workforce is a key component of risk mitigation. Fatigue risk management training should help workers, their managers, and other operational personnel (e.g. scheduling, human resources) understand how to manage work, sleep, and the application of countermeasures in order to maximize performance, safety, and health [122].

Fatigue risk management training and other risk mitigation strategies may be incorporated into a fatigue risk management system (FRMS), which is a proactive, data-driven process whereby an organization undertakes a formal risk management approach to reducing the effects of fatigue in the workplace [121, 252]. An FRMS program involves all stakeholders (workers, management, unions, regulators), includes proactive data collection steps, and adapts to dynamically changing risks so as to be self-improving. The implementation of a FRMS is unique to the needs of a given industry and company, but the elements of FRMS programs are similar across industries (see also Appendix B). A FRMS is often embedded within a larger safety management system (SMS) to allow for integrated risk management. FRMS program managers are typically responsible for developing and implementing policies designed to mitigate fatigue-related risks (e.g. scheduling and rest requirements, and countermeasure use), investigating fatigue-related incidents and accidents, monitoring safety performance indicators, evaluating the impact of work schedules on performance and safety, providing mechanisms for individuals to report fatigue at work, providing recommendations for modifying schedules to improve fatigue-related outcomes, and providing regular training and resources to employees on best practices for managing work, sleep, and the application of countermeasures [121, 124].

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