TP 13620E

BEST PRACTICES COMPENDIUM OF FATIGUE COUNTERMEASURES IN TRANSPORT OPERATIONS

Prepared for
Transportation Development Centre (TDC)
of
Transport Canada

by
Pro Tempo, Inc.

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This report reflects the views of the author and not necessarily those of the Transportation Development Centre.

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16. Abstract

This compendium critically evaluates research findings related to fatigue countermeasures applicable to transport operations. It reviews the strategies used to manage work-related fatigue in the trucking, marine, aviation, and rail industries and makes recommendations for improved management and future research.

The report is divided into the following sections:

- description of the problem of fatigue in multimodal transport operations
- description of the physiological basis of operator fatigue
- critical evaluation of various work and rest schedules, as per regulations, in transport operations
- critical evaluation of different countermeasures
- future research

The report responds to one of the recommendations that emerged from the *Proceedings of the fatigue in transportation workshop: multimodal issues and solutions* (TP 13375).

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16. Résumé

Ce rapport présente une évaluation critique des résultats de recherches sur les mesures de lutte contre la fatigue applicables au secteur des transports. Il passe en revue les stratégies utilisées pour prévenir et combattre la fatigue professionnelle dans les secteurs du camionnage et du transport maritime, aérien et ferroviaire, et formule des recommandations pour améliorer la lutte contre la fatigue et pour la poursuite de la recherche dans ce domaine.

Le recueil est subdivisé en plusieurs sections :

- Le problème de la fatigue dans les divers modes de transport
- Les fondements physiologiques de la fatigue des opérateurs de véhicules
- L'évaluation critique des divers horaires de travail et de repos suivant la réglementation dans les transports
- L'évaluation critique de diverses contre-mesures à la fatigue
- La recherche future

Ce rapport fait suite à une des recommandations du *Compte rendu de l'Atelier sur la fatigue dans les transports : questions et réponses multimodales* (TP 13375).

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EXECUTIVE SUMMARY

This project responds to one of the recommendations emerging from the 1999 *Proceedings of the fatigue in transportation workshop: multimodal issues and solutions* [1]**.** The aim of the compendium is to develop knowledge on fatigue countermeasures applicable to transport operations by critically evaluating research findings. This compendium contains key facts, results, and implementation strategies related to the optimal use of various countermeasures. It reviews the strategies used to manage work-related fatigue in the trucking, marine, aviation, and rail industries. This problem is particularly important for Coast Guard and aircraft operations that often require long work hours, rotating schedules, and rapid changes of work schedule. Without doubt human fatigue is a significant factor in transportation accidents and the compendium can serve to disseminate knowledge on fatigue management. It is divided into the following sections:

- Description of the problem of fatigue in multimodal transport operations
- Description of the physiological basis of operator fatigue
- Critical evaluation of various work and rest schedules, as per regulations, in transport operations
- Critical evaluation of different countermeasures
- Future research

An extensive bibliographical search on Medline and bibliographic databases available through TDC was used to clarify the problem of fatigue in the transportation industry. This comprehensive search also covered the physiological basis of operator fatigue and the field of human alertness, shift work, and chronobiology. A critical evaluation of various strategies to counteract fatigue is provided per mode of transportation. This literature review is comprehensive rather than exhaustive. It addresses key issues relevant to the problem of operator fatigue and makes recommendations to improve its management.

Description of the problem of fatigue in multimodal transport operations

Human factors are involved in more than two-thirds of accidents in transport operations. Accidents are explained to a significant extent by the loss of alertness associated with fatigue. The following outlines critical data by transportation mode.

Trucking industry

- Crashes involving motor vehicles account for 95 percent of all transportation fatalities and most injuries [2]
- The most frequently cited probable cause of accidents is fatigue (31 percent), followed by alcohol or other drugs [3]
- The population at risk is 16-29 years old, especially males, shift workers, untreated patients with sleep apnea syndrome, and narcoleptic patients [4]
- About 28 percent of crashes fatal to the truck occupants only (FTO) and 18 percent of crashes for fatal to non truck occupants (FTN) occur at night [5]
- Approximately 75 percent of crashes result from driver error [6]

- Fall-asleep crashes are likely to be more serious and often take place on highways in non-urban areas, maybe because more long-distance night driving occurs on highways

Marine industry

- Fatigue contributes to 16 percent of critical vessel casualties and 33 percent of injuries [3]
- Sustained (more than 24 hours) periods without sleep are far more common than in any other mode of transportation [7,8]
- Longer than average work week is observed in merchant shipping
- Non-standard work days, extensive night operations, and periods of intense effort, preceded by periods of relative inactivity are frequent and can lead to fatigue-related accidents [7]

Aviation industry

- Nearly 85 percent of accidents occur during the complex tasks of takeoff and landing and are primarily associated with human error [9]
- Fatigue is involved in the higher accident loss in long-haul wide-body operations compared to that for combined short and medium-range fleets [10]
- Some research attributes about 21 percent of accidents directly or indirectly to fatigue [3], but this estimation can be as high as 70 percent [9]
- Sleep debt accumulates in multi-leg trips, such that performance proportionally worsens
- Seventy percent of air traffic controllers (ATCs) report having more difficulty adapting to shift work as they age [11]

Rail industry

- About one-third of train accidents, employee injuries, and deaths are caused by human factors [3]
- Work and rest schedules of railroad and train crews are often more irregular and unpredictable than they are in other transportation modes

Physiological basis of operator fatigue

Because of the high number of fatigue-related accidents, it is important to examine the factors that affect fatigue in all modes of transportation [12]. Fatigue can be caused by extended on-duty and/or awake periods, inadequate sleep quantity, sleep disturbances, disruption of circadian rhythms, and difficult environmental conditions. Individuals vary greatly in their capacity to adjust to work schedules and operators report increasing problems as they age. The following identifies specific factors contributing to the deterioration of alertness by transportation mode.

Trucking industry [2-4,6,9,13]

- Reduced amount of sleep in the past 24 hours
- Split sleep patterns (i.e., sleep bouts consistently under 6 hours)
- Schedule irregularity

- Use of sleeper berths, which promotes split sleeping that can result in impaired performance
- Inverted duty/sleep periods
- Longer hours awake and lower sleep duration
- Sedating drugs, alcohol, and sleep disorders
- On-duty tasks other than driving, such as paper work, loading, and unloading
- The strongest and most consistent predictor of drivers' fatigue is time of day

Marine industry [7,14,15]

- Lack of regular, adequate, or uninterrupted sleep
- Exposure to stressful conditions
- Crew discontinuity (increased turnover of crew members)
- Reduced level of training
- Paid overtime with increase in on-duty time
- Paperwork burden
- Unpredictable arrival and departure times
- Long duty hours (especially those in excess of 75 days)
- Inflexible work-rule and unpredictable sailing schedules
- Lack of port-relief crews and/or incompetent relief
- Ship-design factors, such as lack of automation and labour-saving devices, unreliable equipment, noise, vibration, extreme temperatures, and ship motion
- Physical/environmental factors such as weather conditions, violent-motion environment, frequent deck work under extreme weather conditions

Aviation industry [9-11,16-21]

- Acute and cumulative sleep deprivation
- Misalignment between endogenous circadian rhythms and the local clock time
- Double burden of shift work and jet lag with irregular and unpredictable exposure to light and darkness
- Long duty hours
- Long periods of inactivity and lowered sensory input
- Reserve flight status making it harder to know the flight schedule in advance
- Long duty periods and early morning hours
- Cockpit environment that promotes sleepiness
- Multiple layovers
- Long-haul flights, especially eastward flights with more than five time zones
- Lack of proper sleep
- Work environment, emotional stress, and individual factors
- Moderate or low levels of activity at night for ATCs

Rail industry [9,22,23]

- Extended duty time and excessive working hours
- Time-of-day with greater difficulties reported at sunrise after an overnight shift
- Night work
- Shift starting in the middle of the night
- Work schedule unpredictability
- Being on call
- Higher levels of start time variability
- Long commutes and waiting times before beginning work
- Sleep disorders
- Reduced duration of the main sleep episode
- Unsatisfactory conditions for sleeping at some terminals
- Boredom or cognitive "underload"

Critical evaluation of various work and rest schedules, as per regulations, in transport operations

Several regulations have been implemented to control the hours of service (HOS) or the time on duty in the transport industry. Most are based on outdated rules that do not optimize safety and productivity, and do not take into account the physiology of the sleep-wake cycle [24]. Exemptions to prescriptive HOS rules are possible in case of unforeseen operational circumstances. Most of the time, the criteria for exemptions are unclear and based on workload and operator judgment. Across all modes of transportation, humans are known to be relatively poor judges of their level of sleepiness. This inevitably increases the risk of fatigue-related incidents. Based on these considerations, a variety of schedules have been implemented in various transportation modes. In the trucking and marine industries, several studies have compared the effects of specific shift schedules on sleep, vigilance, and performance levels. Fewer studies have been carried out in the aviation and rail industries. Key aspects of these regulations and schedules are outlined in the following.

Trucking industry [25-27]

- The Canadian HOS allows a maximum of 13 hours of driving within a 15-hour duty period before an 8-hour rest period
- A maximum of 60 hours on duty in seven days or 70 hours on-duty in an 8-day period is allowed
- After a nap, the level of alertness improves the most after 3 to 5 hours
- Evidence of cumulative fatigue is observed across successive driving days
- 13 hours of night driving for 4 consecutive days is associated with a substantial sleep debt (average sleep duration of 3.8 hours/night)
- 10 hours of day driving for 5 days is associated with moderate sleep debt (average sleep duration of 5.4 hours/night)
- Drowsiness is greater at night with peak levels from late evening until dawn

- 36-hour off-duty period may be marginal for day-start drivers, but is inadequate for night-start drivers
- For drivers on consecutive night-shift cycles, even a 60-hour off-duty period would not eliminate the cumulative sleep debt

Marine industry [14,15,28,29]

- Current regulations impose a minimum of 6 consecutive hours of rest per 24-hour period and a minimum of 16 hours of rest per 48-hour period
- A minimum of six hours and a maximum of 18 hours should separate the end of a rest period and the beginning of the following one
- Many watchkeepers now operate on a two-crew "layday" system using a 6 hours-on/6 hours-off schedule, over a 28-day period, followed by a 28-day period of rest
- In the Western region, a 12-hour on/ 12-hour off schedule is used
- Comparison of the 4&8 and the 6&6 schedules revealed that the total duration of sleep per day is restricted to 330 minutes
- Sleep reduction is worse for night shifts (315 minutes per day)
- Cumulative sleep debt occurs over time (after two weeks on board) and could affect performance levels, motivation, and the quality of crew interaction
- Cumulative sleep debt could be of particular concern in non-routine situations and marine emergencies
- Extension of icebreaking activity beyond eight days in a crewing period negatively affects crew state and subjective alertness
- Personnel on the 12&12 watch had the greatest opportunity for sleep quantity and quality followed by personnel on the 4&8 and then those on the 6&6
- Crew on the 12&12 night watch do not adapt completely to a night routine during an extended 42-day trip

Aviation industry [11,30-32]

- A maximum of 14 consecutive hours of flight duty is allowed in any 24 consecutive hours
- A maximum of 15 consecutive hours of flight duty is allowed in any 24 consecutive hours if the rest period prior to the flight is at least 24 hours
- Flight duty may be extended beyond the maximum flight duty times as a result of unforeseen operational circumstances
- Flight crew should be provided with a minimum of 36 consecutive hours free from duty within each 7 consecutive days
- Flight crew should be provided with a minimum of 3 consecutive days free from duty within each 17 consecutive days
- Thirty-six hours, averaged over a one-year period, should constitute the work week of an ATC
- ATC shifts are between six and eleven hours
- A minimum of ten hours separates the completion of an ATC's previous shift and the beginning of the next one

- ATC shift cycles comprise seventeen days of work and eleven days of rest over a 28-day period
- ATC shifts are scheduled over 4-6 days of work
- ATC days of rest are consecutive and must not be fewer than three
- No difference is observed in ATC performance between a 10-hour 4-day rotating schedule and an 8-hour 2-2-1 schedule; a daily sleep debt occurs in both and sleep gets progressively shorter with the number of successive shifts
- The night shift is associated with an increase in the occurrence of falling asleep while driving to or from work
- Sleep debt is worse after night shifts
- A counterclockwise rotating schedule with quick changes from evening to day and day to night shifts is associated with more severe sleep deprivation
- ATCs with 1-2 quick shift changes per week (i.e., under 12 hours off between shifts) sleep less on all shifts
- Early morning shifts (06:00-08:00) are associated with reduced total sleep time (6 hours/night) and impaired performance during the morning peak of activity
- Counterclockwise, rapidly rotating schedules are associated with a rapid decline in sleep duration across successive shifts and a decline in alertness at the end of a shift

Rail industry [23,33]

- The Canadian work rules allow a maximum of 18 hours per day of duty time
- Performance deteriorates on 12 work-12 rest-8 work or on 12 work-8 rest-8 work schedules
- No differences were observed between these schedules in terms of performance or sleep pattern, but they did not take place during the critical time of day, i.e., at dawn
- Few studies compared the effects of various work and rest schedules in rail operations

Critical evaluation of different countermeasures

The most effective countermeasures are based on physiology and should be applicable to all modes of transportation. Strictly speaking, nothing but sleep restoration effectively compensates for sleep debt. Work and rest schedules should promote adequate recovery sleep, and restrict night shift work, split sleep pattern, or counterclockwise rotation. Strategic napping could be used as a safety valve to improve alertness. However, it should not be a substitute for a proper shift schedule, and its negative effects, namely sleep inertia and disruption of the main sleep episode, must be considered. Technological devices are proposed to assess Fitness-for-Duty/Readiness-to-Perform (FFD/RTP), to provide on-line measurement of alertness, and to initiate intervention algorithms. Comprehensive education programs regarding shift work, work and rest schedules, and proper regimens of health, diet, and rest have been proposed and tested in some, but not all, modes of transportation. The following outlines some of the countermeasures proposed, by transportation mode.

Trucking industry [2-6,9,24,27,34-41]

- Implementation of a fatigue management program with a good education program about sleep and behaviour to prevent drowsy driving
- Incentive programs for accident-free performance
- Health management systems to screen for sleep disorders or other fatigue-related conditions
- Recognized strategies to increase levels of alertness:
  - napping before a long drive
  - strategic napping (10-30 minutes nap) when drowsy while driving
  - coffee (two cups)
- Strategies to increase the level of stimulation (short-lived, of limited value, and not well validated):
  - light physical activity
  - sitting in an uncomfortable position
  - controlled noise
  - interaction with workmates
  - cold/fresh air
  - ingestion of sugar
  - increased lighting
- Reorganization of work and rest schedules:
  - limit night driving
  - minimum of two full nights of sleep after an extended driving period
  - some degree of flexibility in driving hours
  - alternative work schedules, different from HOS regulations, closer to a natural circadian sleep-wake cycle
  - restriction of long duty period (e.g., a maximum of 12 hours driving per day)
  - protected rest and break periods (e.g., a maximum of 5 hours driving before a 30-minute break, a minimum of 9 hours between two consecutive shifts)
- Improved cabin environment (air, temperature, sound, vibrations)
- Improved sleeping facilities
- Technological devices that can be used as "alertometers" and/or to warn about dangerous levels of sleepiness:
  - rumble strips
  - the SNAP (Sonic Nap Alert Pattern)
  - sophisticated alertness detection technology that could ultimately be housed in vehicle cabs
  - eye closure measures, particularly PERCLOS
  - lane-keeping measures of performance such as lane excursion and lane deviation
  - psychomotor vigilance task (PVT)
- Fitness-for-Duty/Readiness-to-Perform (FFD/RTP) testing
- Fatigue management algorithms based on technology such as wrist/activity monitor and sleep/wakefulness models
- Intelligent Transportation System (ITS) for continuous in-vehicle driver monitoring. ITS could incorporate an intervention algorithm (advisory messages and/or an alerting stimulus)

Marine industry [14,29]

- Selection of watchkeepers according to their capacity to adapt to irregular schedules
- Consideration of crew preference and age in work scheduling
- Continued evaluation of various work and rest schedules
- Adequate organization of work and rest schedules
- Improved opportunities for strategic rests
- Additional rest and improved safety measures when icebreaking occurs late in the duty cycle
- Opportunity for adequate sleep for at least two nights
- Consideration of workload and circadian factors in addition to the hours of duty
- Limitation of overtime to an operationally viable minimum
- Implementation of a fatigue management program with a good education program on sleep and circadian rhythms physiology

Aviation industry [9-11,16,18,19,42-52]

- Attempts to maintain good health by regular exercise, good diet, and adequate amount of sleep
- Education programs for ATCs, their managers, and families on sleep strategies and hygiene
- Avoidance of overtime after consecutive night shifts, double quick-changes, or any compressed schedule
- Optimal scheduling with appropriate recovery time
- Strategic 20-40 minute naps during the cruise portion of long-haul flights, especially in exclusively long-haul flight operations
- Use of cockpit rest as a safety valve only, and not to replace appropriate flight and duty time scheduling
- Scheduling should be more appropriate for sleep and circadian physiology and take into account the time of departure, the number of time zones, and the impact of a multileg flight
- Incorporation of the concept of “anchor sleep” into the work schedule
- Improvement of on-board sleep facilities
- Implementation of a good education program on the effects of napping, sleep inertia, circadian rhythms, and life style habits
- Judicious use of hypnotics, exogenous melatonin, or bright-light exposure are possible, but still at the investigation stage

Rail industry [3,9,23,53]

- Obtaining a good solid sleep period before a trip
- Strategic napping en route
- Quality sleeping areas while away from home
- Cooperative efforts to reduce the element of unpredictability in work schedules
- Protected zones for rest, taking into account the travel time to and from home
- Fatigue management programs with lifestyle training for employees and their families, as well as screening for sleep disorders

- Improvement of work/rest schedules with reduction of night work
- Boarding and bunk car improvement
- Improvement in commuting home
- Technology working as “alertometers” or to monitor train position, speed limit infractions, and unsafe braking distances

Recommendations

Cooperative efforts are needed at several levels to promote a fast and valuable transfer of knowledge to real-life situations. The following research and implementation approaches are recommended:

- Provide comprehensive education programs on shift work, work and rest schedules, and proper regimens of health, diet, and rest
- Implement fatigue management programs in all transportation industries to educate drivers, navigators, pilots, ATCs, family members, unions, management, governmental agencies, and politicians on the safety issues related to fatigue and sleep loss
- Promote behaviour-based safety approaches and self-management with performance feedback through measurement technologies
- Incorporate the latest research on sleep and circadian rhythms into work scheduling
- Limit or avoid 12-hour shifts
- Limit or avoid counterclockwise rotating schedules
- Improve the regularity of duty periods on reserve and on-call assignment and reduce the element of unpredictability
- Promote a good solid night of sleep prior to a trip
- Encourage strategic napping en route, especially during night shift or on the cruise portion of long-haul flight operations
- Limit night shifts to a succession of two to three consecutive nights
- Avoid 12-hour night shifts
- Provide a minimum of two full days of rest after an extended duty period, especially if it involved night work
- Provide a minimum of nine hours of rest between two consecutive shifts
- Limit overtime to an operationally viable minimum
- Increase the number of rest areas nationwide
- Increase the visual signals and number of rumble strips on highways
- Provide adequate areas for strategic napping on board ships, aircraft, trains, trucks
- Negotiate special arrangements with hotels such that aircrew members can recuperate from jet lag and night work
- Improve commuting home arrangements
- Support research to develop reliable and practical technologies to detect and alleviate drowsiness while operating a vehicle, ship, train, or aircraft
- Support research to develop tools to better assess the influence on the endogenous circadian system in the field

SOMMAIRE

Ce projet fait suite à une des recommandations du *Compte rendu de l'Atelier sur la fatigue dans les transports : questions et réponses multimodales*, paru en 1999 [1]. Le but de ce recueil est d'établir une base de connaissances sur les contre-mesures à la fatigue applicables au secteur des transports, par une évaluation critique des résultats de recherches récentes. Il présente des faits essentiels, des résultats d'études et des méthodes de mise en oeuvre optimale de diverses contre-mesures. Puis, il passe en revue les stratégies utilisées pour lutter contre la fatigue professionnelle dans les secteurs du camionnage et du transport maritime, aérien et ferroviaire. Le problème de la fatigue revêt une importance toute particulière pour les activités de la Garde côtière et les opérations aériennes, souvent caractérisées par de longues heures de travail, des horaires rotatifs et des changements rapides d'horaire. Nul doute que la fatigue joue un rôle important dans les accidents de transport : le présent recueil se veut un outil de diffusion des connaissances sur la lutte contre la fatigue. Il comporte les sections suivantes :

- Le problème de la fatigue dans les divers modes de transport
- Les fondements physiologiques de la fatigue des opérateurs de véhicules
- L'évaluation critique des divers horaires de travail et de repos suivant la réglementation dans les transports
- L'évaluation critique de diverses contre-mesures à la fatigue
- La recherche future

Une recherche poussée dans la base de données Medline et dans d'autres bases de données bibliographiques accessibles via le CDT a permis de mieux cerner le problème de la fatigue dans les transports. Cette recherche a aussi porté sur les fondements physiologiques de la fatigue des opérateurs de véhicules ainsi que sur la vigilance, le travail posté et la chronobiologie. Une évaluation critique de diverses mesures de lutte contre la fatigue est offerte, par mode de transport. Davantage compréhensive qu'exhaustive, cette recherche documentaire fait le tour des grandes questions reliées au problème de la fatigue des opérateurs de véhicules et formule des recommandations pour mieux la contrôler.

Le problème de la fatigue dans les divers modes de transport

Les facteurs humains contribuent à plus des deux tiers des accidents qui surviennent dans le secteur des transports. Ces accidents sont attribuables en grande partie à la baisse de vigilance qui accompagne la fatigue. Voici quelques faits cruciaux, par mode de transport.

Camionnage

- Les accidents mettant en cause des véhicules automobiles comptent pour 95 p. cent de tous les décès et pour la plupart des blessures reliés aux transports [2]
- La fatigue figure au premier rang des causes probables évoquées pour expliquer ces accidents, (31 p. cent), suivie de l'alcool ou d'autres drogues [3]

- Les personnes âgées de 16 à 29 ans, et surtout les personnes de sexe masculin, les travailleurs par quarts de travail, les personnes atteintes du syndrome d'apnées du sommeil et qui ne sont pas traitées, et les patients narcoleptiques composent la population à risque [4]
- Environ 28 p. cent des accidents qui se soldent par la mort d'occupants du camion seulement, et 18 p. cent des accidents entraînant la mort d'autres personnes que les occupants du camion surviennent la nuit [5]
- Quelque 75 p. cent des accidents sont causés par une erreur du conducteur [6]
- Les accidents dus à l'endormissement du conducteur sont généralement plus graves que les accidents dus à d'autres causes et ont souvent lieu sur les autoroutes, en dehors des centres urbains. Cela peut être dû au fait que les conducteurs choisissent davantage les autoroutes pour les longs trajets de nuit

Transport maritime

- La fatigue contribue à 16 p. cent des décès et à 33 p. cent des blessures découlant d'accidents maritimes [3]
- Les longues périodes de veille (plus de 24 heures) sont beaucoup plus courantes dans ce mode de transport que dans les autres [7,8]
- La durée de la semaine de travail est plus longue que la moyenne dans la marine marchande
- Des jours de travail non standard, des périodes prolongées de travail de nuit et des épisodes d'effort intense faisant suite à des périodes d'inactivité relative sont monnaie courante et peuvent être à l'origine d'accidents reliés à la fatigue [7]

Transport aérien

- Près de 85 p. cent des accidents surviennent pendant les phases complexes du décollage et de l'atterrissage et sont la plupart du temps associés à une erreur humaine [9]
- Les exploitants de gros porteurs de type long-courrier subissent davantage de pertes par accident que les exploitants d'avions court et moyen-courrier [10]
- Selon certaines études, quelque 21 p. cent des accidents sont dus directement ou indirectement à la fatigue [3], mais cette estimation atteint parfois 70 p. cent [9]
- Au cours de vols multi-tronçons, le déficit de sommeil s'aggrave et la performance diminue d'autant
- Soixante-dix pour cent des contrôleurs de la circulation aérienne (CCA) disent avoir plus de difficulté à s'adapter au travail posté à mesure qu'ils avancent en âge [11]

Transport ferroviaire

- Environ un tiers des accidents ferroviaires, des blessures du personnel et des décès sont dus à des facteurs humains [3]
- Les horaires de travail et les périodes de repos des équipages de conduite et des équipes de voie sont souvent plus irréguliers et imprévisibles que dans les autres modes de transport

Les fondements physiologiques de la fatigue des opérateurs de véhicules

Étant donné le grand nombre d'accidents reliés à la fatigue, il est important d'examiner les facteurs qui jouent sur la fatigue dans tous les modes de transport [12]. La fatigue peut être causée par des périodes en service/de veille prolongées, un sommeil insuffisant, des troubles du sommeil, la perturbation du rythme circadien, et des conditions environnementales non propices au sommeil. Chaque personne possède sa capacité propre de s'adapter aux horaires de travail et les opérateurs de véhicules ont davantage de difficulté à s'adapter à mesure qu'ils vieillissent. Voici des facteurs précis qui contribuent à la dégradation de la vigilance, selon le mode de transport.

Camionnage [2-4,6,9,13]

- Période réduite de sommeil dans les 24 dernières heures
- Sommeil fractionné (périodes de sommeil systématiquement inférieures à 6 heures)
- Horaire irrégulier
- Sommeil pris dans une couchette, ce qui conduit facilement au fractionnement du sommeil, qui peut entraîner à son tour une baisse de performance
- Inversion des périodes de service/repos
- Longues heures de veille et courtes périodes de sommeil
- Consommation de sédatifs, d'alcool, troubles du sommeil
- Nécessité d'effectuer d'autres tâches que la conduite : écriture, chargement, déchargement
- L'heure du jour ou de la nuit constitue le plus puissant et le plus sûr prédicteur de la fatigue des conducteurs

Transport maritime [7,14,15]

- Difficulté de bénéficier de périodes de sommeil régulières, de durée adéquate et ininterrompues
- Exposition à des conditions génératrices de stress
- Instabilité de l'équipage (roulement rapide de l'effectif)
- Formation réduite
- Heures supplémentaires payées, allongement des heures de service
- Paperasse
- Heures d'arrivée et de départ imprévisibles
- Longues heures de service (en particulier lors d'affectations de plus de 75 jours)
- Conditions de travail rigides et calendriers de navigation imprévisibles
- Pénurie d'équipes de relève dans les ports et/ou équipes de relève incompétentes
- Facteurs reliés au navire : automatisation et mécanisation insuffisantes, équipements non fiables, bruits, vibrations, températures extrêmes, mouvements du navire
- Facteurs physiques/environnementaux : conditions météorologiques, mouvements violents du navire, travail sur le pont dans des conditions météorologiques extrêmes

Transport aérien [9-11,16-21]

- Déficit aigu et cumulatif de sommeil
- Décalage entre les rythmes circadiens endogènes et l'heure locale
- Double fardeau du travail posté et du décalage horaire, associé à une exposition irrégulière et imprévisible à la noirceur et à la lumière
- Longues heures de service
- Longues périodes d’inactivité et de faible stimulation sensorielle
- Le statut d’employé «en disponibilité» empêche de connaître à l’avance son horaire
- Longues périodes de service commençant tôt le matin
- Environnement du poste de pilotage propice au sommeil
- Nombreuses périodes de repos prises loin du domicile
- Vols long-courriers franchissant plus de cinq fuseaux horaires (notamment les vols d’ouest en est)
- Manque de sommeil réparateur
- Milieu de travail, stress émotif, facteurs individuels
- Activité faible ou modérée la nuit pour les CCA

Transport ferroviaire [9,22,23]

- Longues heures de service et nombre excessif d’heures de travail
- Heure du jour, la pire heure étant l’aube, après une nuit de travail
- Travail de nuit
- Quart de travail commençant au milieu de la nuit
- Horaire de travail imprévisible
- Statut en disponibilité
- Variabilité de l’heure du début de la période de travail
- Longs trajets du domicile au travail et périodes d’attente avant de commencer le travail
- Troubles du sommeil
- Période principale de sommeil écourtée
- Installations non propices au sommeil à certains terminaux
- Ennui, insuffisance de stimulus cognitifs

L’évaluation critique des divers horaires de travail et de repos suivant la réglementation dans les transports

Le secteur des transports est régi par plusieurs règlements sur les heures de service (HS). La plupart comportent des règles dépassées, qui n’optimisent en rien la sécurité et la productivité, et qui ne tiennent pas compte de la physiologie du cycle veille-sommeil [24]. Il est possible, en cas de situation imprévue, de déroger aux règles sur les HS, même si la plupart des règlements sont flous quant aux motifs pouvant justifier une telle dérogation : la charge de travail et le jugement du conducteur constituent généralement les facteurs déterminants. Dans tous les modes de transport, l’être humain est reconnu pour être un assez mauvais juge de son degré de somnolence. Cette situation augmente inévitablement le risque d’incidents attribuables à la fatigue. À la lumière de ces considérations, divers types d'horaires ont été mis en oeuvre dans les différents modes de transport. Plusieurs études effectuées dans les secteurs du camionnage et du transport maritime ont comparé les effets de différents horaires de travail posté sur le sommeil, la vigilance et la performance. Des études du même genre, en moins grand nombre, ont été menées dans les secteurs du transport aérien et du transport ferroviaire. Voici les grandes lignes de ces règlements et un aperçu des horaires qui en découlent.

Camionnage [25-27]

- La réglementation canadienne permet un maximum de 13 heures de conduite et un total de 15 heures de service consécutives, après quoi doit intervenir une période de repos de 8 heures
- Elle permet un maximum de 60 heures de service en 7 jours, et de 70 heures de service en 8 jours
- Après une sieste, la hausse la plus marquée du degré de vigilance se fait sentir au bout de 3 à 5 heures
- Plusieurs jours successifs de conduite entraînent une accumulation de fatigue
- Les horaires de nuit comportant 4 quarts consécutifs de 13 heures de conduite entraînent un important déficit de sommeil (durée moyenne du sommeil : 3,8 heures par période de repos)
- Les horaires de jour comportant 5 quarts consécutifs de 10 heures de conduite sont associés à un déficit modéré du sommeil (durée moyenne du sommeil : 5,4 heures par période de repos)
- La somnolence est plus accentuée la nuit, en particulier de la fin de la soirée jusqu'à l'aube
- Une période de repos de 36 heures est peut-être suffisante pour les conducteurs dont le quart de travail débute le jour, mais elle est insuffisante pour les conducteurs dont le quart de travail débute la nuit
- Même une période de repos de 60 heures ne suffirait pas à combler le déficit de sommeil accumulé par des conducteurs au cours de plusieurs quarts de nuit consécutifs

Transport maritime [14,15,28,29]

- La réglementation en vigueur exige une période de repos d'au moins 6 heures consécutives par période de 24 heures et au moins 16 heures de repos par période de 48 heures
- Des intervalles d'au moins 6 heures et d'au plus 18 heures doivent séparer les périodes de repos
- De nombreuses équipes sur quarts de travail sont maintenant organisées selon un système de rotation de deux équipes, qui pendant 28 jours alternent entre 6 heures de service et 6 heures de repos, puis bénéficient d'une période de repos de 28 jours
- Dans les régions de l'Ouest, on utilise un horaire «douze-douze»
- La comparaison des horaires «quatre-huit» et «six-six» a révélé que la durée totale du sommeil journalier se limite à 330 minutes
- Ce sont les personnes affectées aux quarts de nuit qui dorment le moins (315 minutes par jour)
- Le déficit de sommeil s'alourdit au fil des jours (après deux semaines à bord) et peut altérer les performances et la motivation des membres d'équipage et la qualité de leurs interactions

- Un déficit de sommeil accumulé pourrait être critique si une situation imprévue ou une urgence maritime devait survenir
- Le fait de prolonger au-delà de huit jours la période d'activités de déglaçage lors d'une affectation à bord d'un brise-glace a un impact négatif sur l'état des membres d'équipage et sur leur évaluation subjective de leur degré de vigilance
- C'est à l'horaire «douze-douze» qu'est associé le meilleur sommeil (en quantité et en qualité), suivi par l'horaire «quatre-huit» et l'horaire «six-six»
- Les membres de l'équipe de quart affectés au volet de nuit de l'horaire «douze-douze» ne s'adaptent jamais complètement à la «vie nocturne», même pendant une mission longue de 42 jours

Transport aérien [11,30-32]

- La réglementation permet un maximum de 14 heures consécutives de service de vol au cours d'une période de 24 heures
- Le service de vol peut atteindre 15 heures consécutives au cours d'une période de 24 heures, à condition que la période de repos précédant le vol ait été d'au moins 24 heures
- La durée du service de vol peut être prolongée en cas de circonstances opérationnelles imprévues
- Les membres de l'équipage de conduite doivent bénéficier d'une période de repos d'au moins 36 heures consécutives par période de 7 jours
- Les membres de l'équipage de conduite doivent bénéficier d'une période de repos d'au moins 3 jours consécutifs par période de 17 jours
- La semaine de travail d'un CCA doit comporter une moyenne 36 heures, calculée sur un an
- Les quarts de travail des CCA durent de six à onze heures
- Le CCA doit bénéficier d'une période de repos d'au moins dix heures entre ses quarts de travail
- Les cycles de travail des CCA comportent 17 jours de travail et 11 jours de repos sur une période de 28 jours
- L'horaire d'un CCA est réparti sur quatre à six jours de travail
- Les périodes de repos des CCA doivent compter un minimum de trois jours
- Aucune différence n'est observée, au chapitre de la performance des CCA, entre un horaire rotatif comportant des cycles de 4 quarts de 10 heures et le système de rotation rapide, dit «2-2-1», avec quarts de 8 heures; dans les deux cas, on note un déficit de sommeil et une diminution constante de la durée du sommeil pendant la semaine de travail
- Le quart de nuit est associé à une augmentation des cas d'endormissement pendant le trajet entre le travail et le domicile
- Le déficit de sommeil s'aggrave au fil des quarts de nuit
- L'horaire à rotation rapide, qui comporte des changements rapides de quarts (du soir au jour et du jour à la nuit) entraîne les plus grandes privations de sommeil
- Les CCA qui subissent un ou deux changements rapides de quart par semaine (c.-à-d. moins de 12 heures de repos entre les quarts) dorment moins, peu importe le quart (jour, soir, nuit)

- Les quarts débutant tôt le matin (entre 6 h et 8 h) sont associés à une faible durée du sommeil (6 heures/nuit) et à une perturbation de la performance au cours de la période de pointe du matin
- Les horaires à rotation rapide entraînent une diminution marquée du temps de sommeil au cours du cycle de travail et une baisse de la vigilance vers la fin d'un quart

Transport ferroviaire [23,33]

- La réglementation canadienne permet un maximum de 18 heures de service par jour
- Les horaires de type «12-12-8» (travail-repos-travail) ou de type «12-8-8» entraînent une altération de la performance
- Aucune différence n'a été observée entre ces horaires quant à la performance ou au sommeil, mais aucune des périodes de travail ne coïncidait avec la période critique de la journée, soit les petites heures du matin
- Il existe peu de rapports de recherche sur les effets des divers horaires de travail et de repos dans le secteur ferroviaire

L'évaluation critique de diverses contre-mesures à la fatigue

Lorsqu'il s'agit de lutter contre la fatigue, les contre-mesures les plus efficaces sont de nature physiologique et elles s'appliquent, en principe, à tous les modes de transport. À strictement parler, il n'y a que le sommeil pour combler le manque de sommeil. Les horaires de travail doivent être organisés de façon à permettre aux employés de récupérer pleinement, et ils doivent comporter le moins de travail de nuit possible, de périodes de sommeil fractionnées et de rotations rapides. Le fait de faire une sieste peut servir de soupape de sûreté pour rétablir la vigilance. Mais les siestes ne peuvent jamais remplacer un horaire bien fait; sans compter leur effets négatifs, comme l'inertie due au sommeil et la perturbation de la période de sommeil principale. Des dispositifs techniques sont offerts pour évaluer l'aptitude au travail/l'aptitude à la tâche, pour mesurer en ligne le degré de vigilance et pour déclencher des algorithmes d'intervention. Des programmes de formation sur le travail posté, les horaires de travail et de repos, l'hygiène du sommeil, l'alimentation et le repos ont été proposés et mis à l'essai dans certains modes de transport. Voici quelques-unes des contre-mesures proposées, par mode de transport.

Camionnage [2-6,9,24,27,34-41]

- Mise en oeuvre d'un programme de lutte contre la fatigue assorti d'un programme de formation sur le sommeil et sur les comportements à adopter pour prévenir la somnolence au volant
- Programmes d'incitatifs pour la conduite sans accident
- Systèmes de dépistage des troubles du sommeil ou d'autres états propres à induire la fatigue
- Moyens reconnus de promouvoir la vigilance :
  - faire une sieste avant un long voyage
  - faire une sieste (de 10 à 30 minutes) dès que l'on se sent somnolent au volant
  - boire du café (deux tasses)

- Mesures pour augmenter le niveau de stimulation (à effet de courte durée, de valeur limitée, et non validées) :
  - se livrer à une légère activité physique
  - prendre une position assise inconfortable
  - prévoir un bruit contrôlé dans la cabine
  - interagir avec ses compagnons de travail
  - faire entrer de l’air froid/frais dans la cabine
  - ingérer du sucre
  - intensifier l’éclairage
- Réaménagement des horaires de travail et de repos :
  - limiter la conduite de nuit
  - prévoir au moins deux nuits complètes de sommeil après une longue période de conduite
  - offrir une certaine souplesse pour ce qui est des heures de conduite
  - proposer d’autres horaires de travail, différents de ceux prescrits par les règles sur les HS, qui se rapprochent davantage du cycle circadien naturel de veille et de sommeil
  - limiter la durée de la période de service (p. ex., un maximum de 12 heures de conduite par jour)
  - prévoir des plages protégées pour les périodes de repos et les pauses (p. ex., maximum de 5 heures de conduite avant une pause de 30 minutes, minimum de 9 heures de repos entre deux quarts consécutifs)
- Amélioration des conditions environnementales dans la cabine (air, température, son, vibrations)
- Amélioration des installations de repos
- Dispositifs techniques pouvant servir de «moniteurs de vigilance» et/ou alerter le conducteur lorsque son degré de somnolence est dangereusement élevé :
  - zones routières de ralentissement
  - dispositifs SNAP (*Sonic Nap Alert Pattern*) implantés dans l’accotement
  - systèmes complexes de mesure de la vigilance pouvant être intégrés à l’habitacle
  - dispositif de mesure de l’activité oculaire (PERCLOS)
  - dispositif de mesure des écarts par rapport à la voie (incursions intempestives dans les voies adjacentes)
  - tâche psychomotrice de vigilance (PVT)
- Test d’aptitude au travail/d’aptitude à la tâche
- Algorithmes de gestion de la fatigue fondés sur des dispositifs, comme un moniteur de l’activité du poignet, et des modèles de sommeil/veille
- Systèmes de transports intelligents (STI) assurant la surveillance continue du conducteur au volant. Les STI peuvent comporter un algorithme d’intervention (messages et/ou alarmes)

Transport maritime [14,29]

- Sélection des membres d’équipes de quart de travail en fonction de leur capacité de s’adapter à des horaires irréguliers
- Prise en compte des préférences et de l’âge des membres des équipes de quart lors de l’établissement des horaires de travail
- Évaluation continue des divers horaires de travail et de repos

- Organisation adéquate des horaires de travail et des périodes de repos
- Augmentation des pauses permettant de faire des siestes
- Période de repos additionnelle et intensification des mesures de sécurité lorsque les activités de déglaçage ont lieu tard dans le cycle de travail
- Période de repos suffisante pour permettre au moins deux bonnes nuits de sommeil
- Prise en compte de la charge de travail et des rythmes circadiens, en plus des heures de service
- Limitation des heures supplémentaires au strict minimum opérationnellement viable
- Mise en oeuvre d'un programme de gestion de la fatigue assorti d'un bon programme de formation sur la physiologie du sommeil et des rythmes circadiens

Transport aérien [9-11,16,18,19,42-52]

- Se maintenir en santé par des exercices réguliers, un bon régime alimentaire et un sommeil suffisant
- Offrir des programmes de formation sur les stratégies et l'hygiène du sommeil aux CCA, leurs gestionnaires et leurs familles
- Ne pas prévoir d'heures supplémentaires à la suite de quarts de nuit consécutifs, de deux changements de quart rapides, ou au terme d'un horaire comprimé
- Aménager les horaires de façon optimale, en prévoyant des périodes de récupération suffisantes
- Faire des siestes de 20 à 40 minutes pendant le régime de croisière des vols long-courriers, surtout dans le cas où l'horaire est constitué exclusivement de vols long-courriers
- Considérer les périodes de repos dans le poste de pilotage uniquement comme une soupape de sûreté, qui ne doivent pas justifier un mauvais aménagement de l'horaire de vol et de service
- Aménager des horaires plus propices au sommeil et davantage en accord avec les rythmes circadiens, et tenir compte de l'heure de départ, du nombre de fuseaux horaires franchis, et des répercussions d'un vol multi-tronçons
- Aménager les horaires de travail en y incorporant des «périodes principales de sommeil »
- Améliorer les installations de repos à bord des aéronefs
- Mettre en oeuvre un programme de formation sur les effets des siestes, l'inertie due au sommeil, les rythmes circadiens et les habitudes de vie
- Un recours judicieux aux hypnotiques, à la mélatonine exogène ou à la photothérapie (exposition à une lumière vive) peut aider à lutter contre la fatigue, mais ces techniques sont encore l'objet d'études

Transport ferroviaire [3,9,23,53]

- Bonne période de sommeil ininterrompu avant le début d'un voyage
- Siestes en cours de route
- Installations de repos de qualité à la disposition du personnel en déplacement
- Efforts concertés pour réduire l'imprévisibilité des horaires de travail

- Plages de repos protégées, dont la durée tient compte du temps de déplacement entre le travail et le domicile
- Programmes de gestion de la fatigue et formation pour un meilleur style de vie s'adressant aux employés et à leur famille, et dépistage des troubles du sommeil
- Meilleur aménagement des horaires de travail/périodes de repos et réduction du travail de nuit
- Amélioration des voitures-logements et des wagons-dortoirs
- Amélioration des trajets entre le travail et le domicile
- Dispositifs utilisés pour «mesurer la vigilance», par une surveillance de la position du train, des dépassements de la vitesse permise et des distances de freinage excessives

La recherche future

Des efforts concertés s'imposent à plusieurs niveaux pour promouvoir un transfert rapide et efficace des connaissances aux situations de la vie réelle. Voici quelques recommandations touchant la recherche et la mise en oeuvre de stratégies de lutte contre la fatigue :

- Offrir des programmes de formation complets sur le travail posté, les horaires de travail et de repos, les habitudes de vie saines, l'alimentation et le repos
- Mettre en oeuvre des programmes de gestion de la fatigue dans tous les secteurs du transport afin de sensibiliser les conducteurs, les navigateurs, les pilotes, les contrôleurs de la circulation aérienne, les membres de leurs familles, les syndicats, les cadres, les organismes gouvernementaux et les politiciens aux risques engendrés par la fatigue et le manque de sommeil
- Promouvoir des approches de la sécurité fondées sur le comportement et l'autogestion, faisant notamment appel à des instruments de mesure donnant une rétroaction sur la performance
- Tenir compte des dernières découvertes sur le sommeil et les rythmes circadiens lors de l'établissement des horaires
- Limiter ou éviter les quarts de 12 heures
- Limiter ou éviter les horaires à rotation rapide
- Améliorer la régularité des périodes de service des employés en disponibilité et réduire au minimum l'imprévisibilité de ces horaires
- Faciliter la prise d'une bonne nuit de sommeil avant un voyage
- Encourager les siestes en cours de route, particulièrement pendant les quarts de nuit ou en régime de croisière des vols long-courriers
- Aménager des horaires comportant un maximum de deux ou trois quarts de nuit consécutifs
- Éviter les quarts de nuit de 12 heures
- Aménager des horaires comportant un minimum de deux jours complets de repos après un long cycle de travail, surtout si ce cycle était constitué de quarts de nuit
- Accorder au moins neuf heures de repos entre deux quarts de travail
- Limiter les heures supplémentaires au minimum opérationnellement viable
- Aménager de nouvelles haltes routières partout au pays

- Augmenter la signalisation visuelle et le nombre de zones routières de ralentissement sur les routes
- Aménager des aires pour les siestes à bord des navires, des aéronefs, des trains et des camions
- Négocier des arrangements spéciaux avec les hôtels afin de permettre aux équipages navigants de se remettre du décalage horaire et du travail de nuit
- Faciliter le transport entre le travail et le domicile
- Soutenir la recherche visant le développement de techniques fiables et commodes pour détecter la somnolence des opérateurs de camions, de navires, de trains ou d'aéronefs et pour la contrôler
- Soutenir la recherche visant le développement d'outils pour mieux évaluer en situation réelle l'influence du système circadien endogène

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1 INTRODUCTION

This project responds to one of the recommendations emerging from the 1999 *Proceedings of the fatigue in transportation workshop: multimodal issues and solutions* [2].

To operate a vehicle, a ship, a train, or an aircraft, the operator must integrate a wide variety of cues and respond efficiently to a number of elements that might pose a threat if ignored [2]. Human errors underlie more than two-thirds of accidents in transport operations and are largely explained by the loss of alertness associated with fatigue. Fatigue is characterized by decreased alertness, slower information processing and decision making, slower reaction time, poor judgment, reduced performance on attention-based tasks, and deficits in processing and integrating information [4,36,54]. Motivation can only attenuate fatigue for a brief period of time. Signs of performance impairment, such as attentional lapses, mental blocks, microsleeps, and increase of time-on-task, are frequent in commercial truck drivers, ice navigators, and ship and airline crews. This raises operational safety issues.

Studies across all modes of transportation reveal that subjective estimates of vigilance are usually very poor. Operators underestimate their fatigue because they are influenced by workload or external stimulation. Unfortunately, intense sleepiness does occur and can produce transient perceptual distortions and judgment errors that result in a significant increase of fatigue-related accidents or fatalities. These are more common when sustained visual attention to a routine task is required, when the environment is unstimulating, during extended work hours, or during the circadian night. The work environment, such as the cockpit of an aircraft, the cabin of a commercial truck, or the movement and noise onboard a ship or a train, can contribute to further deterioration of vigilance and increased fatigue.

Fatigue can be caused by extended on-duty and/or awake periods, inadequate sleep quantity/quality, and disruption of circadian rhythms. Substantial sleep disruption generally occurs during marine watches, multitrip commercial operations, and multi-leg aircraft trips. It inevitably leads to less effective rest and, in some instances, to fragmented bimodal rhythms [29]. It is well known that fragmented sleep is less effective for recovering from sleep loss. Belenky reports that the effects of sleep deprivation and sleep fragmentation are greatest on complex mental operations. The lack of rest results in loss of judgement and impaired situational awareness. Eight subjects underwent a PET study after an 85-hour sleep deprivation procedure. A decrease in metabolic activity appeared in the prefrontal cortex, the thalamus, the singular gyri and the medial/inferior lateral parietal cortex [54]. These areas affect attention, higher order mental intregration, and judgement.

Fluctuations in body temperature have also been positively correlated with specific aspects of performance including: signal detection; reaction time; alertness; neuromuscular coordination; mathematical processing; and attention [29]. Truck drivers, aircrews, ship crews, and locomotive operators face difficult situations, since they often operate at a time of day when vigilance is typically much lower and the external environment is much darker, thus further promoting sleepiness [9]. Those on-duty during the night, working for 12 or 14 hours per shift, are awake for an extended period and suffer from the greatest sleep loss [9]. Sleep episodes after completion of the night shift are also impaired, due to the natural tendency of the endogenous circadian pacemaker to “wake up” as the day progresses.

This compendium reviews the basis for operator fatigue and fatigue countermeasures applicable to multimodal transport operations.

2 THE PROBLEM OF FATIGUE

2.1 Trucking Industry

The important economic union between the U.S. and Canada has resulted in truck transportation growth from 39 percent to 40 percent of all transport activities. Nearly 60 percent of Canada's exports to the U.S. and 80 percent of Canadian imports are moved by trucks [9]. This represents about 30,000 truck movements per day. Fatalities occur in all modes of transportation and crashes involving motor vehicles account for 95 percent of all transportation fatalities and most injuries [2]. It is estimated that 9 percent of the country's fatal accidents and 18 percent of fatalities involve large trucks. The National Highway Traffic Safety Administration (NHTSA) estimates that of about 100,000 police-reported U.S. crashes annually, around 1.5 percent have drowsiness/fatigue as a principal factor [6]. It is widely recognized that fatigue-related crashes are underestimated in police reports, so statistics do not adequately reflect the contributing, as opposed to primary, role that fatigue may play in crashes [13]. Indeed, a large proportion of accidents attributed to driver inattention may be due in part to driver drowsiness/fatigue. Analysis of human factors in heavy truck accidents in 1987-1988 revealed that the most frequently cited probable cause of an accident was fatigue (31 percent), followed by alcohol or other drugs (29 percent)[3]. The evaluation of the role of fatigue in truck driving differs depending on whether drivers or company officials are consulted. In Western Australia, about 10 percent of drivers report that they often experience fatigue on the job whereas only 1 percent of company officials say their drivers have a problem with fatigue [9].

The population at risk is between the ages of 16 and 29, especially males, shift workers, untreated patients with sleep apnea syndrome, and narcoleptic patients [4]. Nearly 75 percent of all crashes fall into three broad categories: rear-end, intersection, and road-departures. Approximately 75 percent of crashes result from driver error [6]. Fall-asleep crashes are likely to be more serious and often take place on highways in non-urban areas, maybe because more long-distance night driving occurs on highways. In these crashes, the driver does not attempt to avoid crashing and is most frequently alone in the vehicle [4]. The percentage of crashes attributed to fatigue is much lower (0.96 percent) in single-unit trucks (SUTs) than in combination-unit trucks or CUTs (1.98 percent). This is largely because CUTs are usually involved in long-haul and 24-hour drives. The percentage of crashes attributed to fatigue is much higher for fatal to the truck occupants only (FTOs) at 10.57 percent than for fatal to non truck occupants (FTNs) at 0.62 percent [13]. These values are consistent with the report that 80 percent of drowsy-driver crashes are single-vehicle roadway departures or collision with parked vehicles [6].

Of particular interest is the period between midnight and 6:00. Drowsy-driver crashes occur predominantly after midnight, with a smaller secondary peak in the mid-afternoon, both for commercial and non-commercial driving [4]. About 28 percent of crashes FTO and 18 percent of crashes FTN occur at night [5]. Night crashes are more likely to be single vehicles and result from lane drifting and falling asleep at the wheel. Driver fatigue is coded in 20 percent of the overnight single-vehicle fatal crashes, but data files based on police accident reports undercount fatigue-related crashes.

2.2 Marine Industry

Despite technological innovations and increased levels of automation on board ships [55], "human error" is still believed to be the most common cause of marine transportation accidents [7]. It is estimated that human fatigue, sleep debt, and circadian rhythm disruptions were a major factor in the loss of 52 vessels recorded in European waters between 1984 and 1992 [56]. A recent safety report by the U.S. Department of Transportation estimates that fatigue contributed to 16 percent of critical vessel casualties and 33 percent of injuries [3]. Several fatigue-related investigations and studies conducted since May 1989 are summarized in this report. They include the grounding of the tankship *Exxon Valdez* in March 1989, the sinking of the tug *Barcona* by a U.S. Navy nuclear attack submarine in June 1989, the grounding of a passenger ship in June 1995, and a pipeline rupture and release of fuel oil in November 1998. For economic reasons, ship manning levels are being reduced worldwide and ships are designed to operate with very limited crew [7]. Reports of fatigue among workers in the marine industry are common. Workers are sensitive to conditions leading to sleep fragmentation and circadian rhythm disruption [55]. These include long work hours, split rest/work schedules, and environmental factors. The influence of environmental factors is especially important in operational settings such as Arctic icebreaking, during which Canadian ice navigators are constantly on bridge duty while the ship is moving in ice-infested waters.

To enhance the efficiency and productivity of its Arctic icebreaking operations, the Department of Fisheries and Oceans/Canadian Coast Guard (DFO/CCG) recently proposed extending crewing periods from 28 to 42 days. This would better serve CCG clients by reducing excursions to shore for crew changes, which are expensive and affect client schedules [29]. The potential exists in extended crewing periods for fatigue to accumulate to unacceptable levels, impairing the operational effectiveness of the crew, especially in case of an emergency. To ensure safety of operations, DFO/CCG launched a multiphase field study that provided a unique opportunity to monitor crew members working under a variety of unconventional work/rest schedules for extended periods [14,28,29]. With advances in technology, longer shifts become possible. Marine operations rely on complex tasks with high levels of attention, memory, and vigilance, as well as on newly learned tasks and responses to novel situations [29]. Merchant shipping is also characterized by a longer than average work week, nonstandard work days, extensive night operations, and periods of intense effort, preceded by periods of relative inactivity [7]. In this industry, sustained (more than 24 hours) periods without sleep are far more common than in other modes of transportation [7,8]. Sleep deprivation and performance decrements are presumed to be major contributing factors in a large proportion of marine accidents [7]. Therefore, fatigue remains a matter of concern in the marine environment.

2.3 Aviation Industry

In August 1980, a workshop entitled *Pilot Fatigue and Circadian Desynchronosis* was held in San Francisco to assist NASA in responding to a Congressional request regarding the problem of jet lag. The following statement can be read on page 4 of the workshop report [16]:

> *The initial statements made by the participants indicated that most did not perceive a major problem relating to pilot fatigue or to circadian desychronosis as factors in air safety. As the participants received additional information from their colleagues, these views began to change, at first imperceptibly, so that by the end of the discussion of this question there was general agreement that a problem might exist.*

This reminds us that aircrews and airline administrations can be very bad judges of their level of fatigue or its impact on airline operations. Even though the aviation system has been designed such that performance decrements infrequently lead to accidents, fatigue occurs as a result of sleep deprivation and circadian rhythm disruption. This leads to errors, impaired performance, and fatigue-related accidents with their potentially disastrous consequences. It is now estimated that, in aircraft operations, nearly 85 percent of accidents occur during the complex tasks of takeoff and landing and that these accidents are primarily associated with human error [9]. Fatigue associated with sleep loss and jet lag was involved in the higher accident loss of long-haul wide-body operations compared to that of the combined short and medium-range fleets [10]. According to the U.S. Federal Aviation Administration, about 21 percent accidents are directly or indirectly related to fatigue [3] and some estimates can be as high as 70 percent according to Rosekind [9]. Moreover, each month NASA's Aviation Safety Reporting System receives reports of fatigue-related incidents in long-haul flights such as altitude busts, track deviations, landing without clearance, and improper fuel calculations [10]. The sleep debt accumulates in multi-leg trips such that performance proportionally worsens. This problem is more prevalent than initially believed and affects several classes of employees in the aviation industry. A 1994 TDC report describes a national survey in which 921 air traffic controllers (ATCs) answered 114 questions relating to their job characteristics, sleep, and coping strategies [11]. Among the interviewed ATCs, 70 percent reported having more difficulty adapting to shift work as they age. ATCs between 35 and 44 years of age reported feeling less healthy and more ill than younger or older ATCs. There were regional differences, with Pacific, Quebec, and Ontario ATCs reporting a better Healthy Index and lower illness indices.

2.4 Rail Industry

The U.S. Federal Railway Administration (FRA) estimates that about one-third of train accidents, employee injuries, and deaths are caused by human factors [3]. However, few objective data are available and difficulties arise when we try to identify fatigue as a causal or contributing factor in railroad accidents. We generally rely on indirect or circumstantial evidence, namely witness statements (including those of the operator), hours worked and slept in the previous few days, the time at which the accident occurred, and the regularity or irregularity of the operator's schedule [3]. The work and rest schedules of railroad and train crews are often more irregular and unpredictable than those in other transportation modes. Investigations and studies conducted by the U.S. National Transportation Safety Board (NTSB) since May 1989 in the rail industry documented that fatigue was involved in at least three train collisions and derailments. In these reports, chronic and acute fatigue of engineers or train operators was involved, as a result of the irregularity and unpredictability of their work schedules [3]. For example, details are provided on the Conrail collision between a westbound and an eastbound freight train resulting in fatalities.

The probable cause was that the sleep-deprived train engineer and crew members failed to comply with restrictive signals. The contributing factors were unpredictable work/rest schedules, voluntary lack of proper sleep resulting in chronic and acute fatigue, and inadequate alertness. The engineer did not attempt to get meaningful sleep before anticipated calls to work late and slept less than 2 hours during the 22-24 hours preceding the accident. He reported a failure to eat for 13 hours prior to the accident and the drowsiness might have been worsened by the monotonous environment. These observations indicate that sleep deprivation and circadian rhythm disturbances play a primary role in fatigue-related accidents in the railroad industry, as they do in other modes of transport.

3 PHYSIOLOGICAL BASIS OF OPERATOR FATIGUE

3.1 Trucking Industry

Because of high numbers of heavy truck-related fatalities and the significant role of fatigue, the NTSB initiated a study of 107 single-vehicle heavy truck accidents to examine the factors that affect fatigue [12] (summarized in [3]). For the study, they selected single-vehicle accidents in which the driver survived. Questions were asked on the driver duty and sleep patterns for the 96 hours preceding the accident. They compared the results to those in non-fatigue-related accidents. There was no apparent relationship between fatigue and age, experience, training, or the type of vehicle. Circadian rhythm was clearly related to the risk of accidents. Driving at night with a sleep deficit is far more critical in terms of predicting fatigue-related accidents than simply driving at night. Discriminant analysis indicates that the most critical factors in predicting fatigue-related accidents are the duration of the most recent sleep period, the amount of sleep in the past 24 hours, and split sleep patterns (i.e., sleep bouts consistently less than 6 hours). Schedule irregularity was the major factor discriminating between long-haul and short-haul operations. Drivers involved in fatigue-related accidents had 5.5 hours in their last sleep period. This was 1.4 hours less than the 6.9 hours they reported needing to feel rested and 2.5 hours less than that obtained by drivers in non-fatigue-related accidents (8.0 hours). Drivers involved in fatigue-related accidents obtained 6.9 hours of sleep in the last 24 hours compared to 9.3 hours for drivers in non-fatigue-related accidents.

Hours of Service (HOS) rules do not provide the opportunity to obtain an adequate amount of sleep (i.e., 8 continuous hours). The subjective estimates were very poor, since 80 percent of the drivers rated the quality of their last sleep period as good or excellent. The use of sleeper berths, which allow specific HOS exemptions, promoted split sleeping that can result in performance decrements. About 67 percent of the drivers with irregular schedules had fatigue-related accidents versus 38 percent with regular schedules. About 94 percent of the drivers with inverted duty/sleep periods had a fatigue-related accident. Sleep irregularity and sleep inversion may result in longer hours awake and shorter sleep duration. The drivers who exceeded the HOS regulations (82 percent) had a fatigue-related accident. It was found that 90 percent of regional and long-haul drivers used sleeper berths; 50 percent sometimes sacrificed sleep to maintain delivery schedules; 20 percent usually loaded and unloaded their vehicles; 28 percent reported at least one incident of dozing or falling asleep at the wheel; and the majority stated that they continue to drive even when they are aware of their fatigue. Interestingly, more accidents were reported for drivers paid by the mile.

Other contributing factors were frequently associated with sleep deprivation and extended work periods. For instance, more than 50 percent of the drivers who had violated HOS rules tested positive for some drug abuse [3]. Marijuana was the most prevalent and use of amphetamines, cocaine, and alcohol was observed. In drivers who tested positive for drugs, the risk of accident was similar throughout the day. For drug-free drivers, the risk of crashes increased in certain circumstances (circadian trough, increased exposure). It is recognized that worsening conditions for fatigue are sleep loss, driving pattern, sedating drugs, alcohol, and sleep disorders [4]. An Australian truck safety study revealed that drugs, alcohol, and driving hours are the most critical immediate influences on driver behaviour [34]. Some contributors to fatigue reported by unregulated drivers in Western Australia are: driving long hours (38.2 percent); loading/unloading (33.4 percent); delays in loading (32.4 percent); lack of sleep (32.4 percent); and driving between 2:00-5:00 (21.2 percent)[9]. Log books are routinely falsified by drivers and companies, and it is common to find two sets of log books [3]. Each year, more than 14,000 HOS and log book violations are cited during compliance reviews of American motor carrier operations [5]. About 80 percent of all driver violations represent about 6 percent of drivers inspected annually.

On-duty tasks other than driving can also significantly affect levels of fatigue. A study by the FHWA examined the effects of loading and unloading on driver performance during extended work hours (FHWA-MC-99-140, summarized in [5]). The study consisted of 90-minute sessions of moving boxes before a 14-hour on/10-hour off driving schedule on a simulator over 5 days with 12 hours driving/day. Loading and unloading appeared to exert a mixed effect on driving performance. In the morning, exercise had a short-term invigorating effect on vigilance and response times. Performance deteriorated following afternoon loading/unloading sessions. A cumulative effect was seen on subjective measures of sleepiness and psychomotor vigilance.

3.2 Marine Industry

Fatigue in the marine industry can be influenced by a number of factors, including personal lifestyle, sleep patterns, circadian rhythms, environmental conditions, crew and personal preparation for the crewing period and the watch schedule, and vessel tasking and workload [14]. In a recent study of work/rest schedules on board foreign-registered vessels in the Canadian Arctic, seven ice navigators were interviewed in two groups [15]. In this study, three ice navigators filled out daily logs and self-rating scales on a total of seven voyages in Arctic waters. This study revealed the role of environmental and task conditions, workplace design, and work scheduling in producing fatigue. Fatigue was greater at the end of duty periods compared with the end of sleep/nap periods. More significantly, it was related to time of day, suggesting that endogenous circadian rhythms play a major role in adjusting to work schedules. Another study of 36 extended interviews conducted with officers on five merchant vessels during brief coastal voyages [7] revealed that crew fatigue was affected by three basic mechanisms: the number of hours worked; the ability to get regular and uninterrupted sleep; and exposure to stressful conditions, both mental and physical. Several clusters of factors were identified as contributors to fatigue. A first series of factors, called “organizational factors” suggested that crew discontinuity (increased turnaround of crew members), reduced level of training, paid overtime with increase in on-duty time, and paperwork burden would have a negative impact on crew members’ fatigue. A second series of factors, called “scheduling factors” indicated that unpredictable arrival and departure times, long duty hours (especially in excess of 75 days), inflexible work rules, unpredictable sailing schedules, lack of port-relief crews, and/or incompetent relief were seen as important contributors to crew fatigue. Ship-design factors, such as lack of automation and labour-saving devices, unreliable equipment, noise, vibration, temperature, and ship motion can affect the level of physical stress and the ability to get regular sleep. Physical/environmental factors such as weather conditions, violent motion, and frequent deck work under extreme weather conditions can also affect resistance to fatigue.

3.3 Aviation Industry

Charles Lindbergh and Wiley Post, the first men to fly across the Atlantic Ocean, in 1927 and 1933, respectively, were the first to experience symptoms of jet lag (see [57,58] for a historical perspective). Each year several million travellers suffer from adaptation troubles associated with rapid travel across time zones. These troubles consist of various somatic complaints such as acute insomnia, fatigue, headaches, dizziness, irritability, depression, and digestive and cardiovascular discomforts [57,59-69]. Even if these troubles are transient, they can drastically deteriorate vigilance levels and safety in the transportation industry. They are the result of acute and cumulative sleep deprivation and depend mainly on a misalignment between the internal body time and the local clock time. This phenomenon does not occur on north-south routes and does not differ between outbound and inbound flights [64,65,68,70-74]. Internal phase discrepancies were observed after simulated or real transmeridian flights in the diurnal rhythms of core body temperature, cardiac rhythm, daily secretion of plasma cortisol and melatonin, and urinary excretion of electrolytes and corticosteroids [62,74-81]. A significant deterioration of psychometric variables such as vigilance and cognitive and athletic performance were reported [63,74,80,82-84]. Important perturbations in the duration of sleep episodes, sleep latency, and latency of paradoxical sleep were shown as results of jet lag, using subjective measures and polysomnographic recordings [57,61,62,66,74,85]. The disturbances of daily rhythms and the sleep/wake cycle can take several days [81] or even more than one week to normalize [80]. The rate of adjustment to jet lag depends on the number of time zones, the rapidity with which they are crossed, the direction of the flight (worst for eastward travels), and individual factors such as age and a history of prior jet lag [49,68,84-89]. Air crew are thus at particular risk of suffering from severe and recurrent adaptation troubles because they have to face the double burden of shift work and jet lag with irregular and unpredictable exposure to light and darkness [90,91].

It has been known for several decades that fatigue can build up and that pilot performance degrades as a result of sleep loss, circadian desynchronization associated with time-zone changes, and long duty hours (for a review see [16]). Long periods of inactivity and lowered sensory input, letdown/relaxation/boredom, less than optimal nutrition, and use of alcohol or drugs were identified as contributing factors to fatigue. Fatigue is related to the pilot's level of attention, arousal, and alertness during flight and its effects are different for each person. It requires more processing for those tasks that would otherwise be more automatic. It is believed that fatal errors can be made by highly trained, skilled, and experienced professional pilots [17]. Twelve military pilots flying between Trenton and Zagreb were asked to undergo 20-minute tests with multitask and electroencephalographic (EEG) procedures at least twice during the outbound trip and twice during the return leg of the trip [17]. These tasks were selected because complex information processing always occurs in a context of multitasking and sustained operations, which depend on complex information processing, can be negatively affected by fatigue. It was found that the greatest errors occurred between 23:00 and 08:00, a time when one would expect to see the worst performance according to circadian factors. Age is also important since workers over 40 have more problems adapting to shiftwork. Younger pilots also have their share of difficulties since they are more often on reserve flight status, making it harder to know their schedule in advance [9].

The study of an extreme situation, namely that of five C-141 air crews over 30 days during operation Desert Storm, indicates that extended work periods, reduced sleep periods, night work and circadian dysrhythmia caused by shift work and time-zone crossings were associated with fatigue and pilot error [18]. Flight data, activity logs, oral temperature, and fatigue ratings were obtained every 4 hours for each subject. It was found that 10 hours or less of sleep and 15 hours or more of flight time per 48 hours correlated with high fatigue and reduced performance. Daytime sleep was also often disturbed by daytime activities (lawn mowing, housekeeping) and crew members were often required to work during the trough of their endogenous circadian system [18].

Performance decrements in air transport operations reported to the Aviation Safety Reporting System between 1976-1980 were most often associated with long duty periods and early morning hours [18]. These decrements are worse during the early morning hours corresponding to the circadian nadir of core body temperature. Similar factors can explain the occurrence of undesirable sleepiness in common aircraft operations. Flight crews can experience spontaneous and unplanned sleep episodes in flight [9]. It was found that as much as 120 microsleep events can occur per flight, including 22 during the last 30 minutes of descent and landing [9]. In addition to internal, physiological factors, the role of the external environment should be considered in the occurrence of these unplanned naps, as stated by Curtis Graeber et al. [19]:

> *The cockpit environment, with its constant background noise, dim lighting, and automated systems, can contribute to the difficulty of remaining vigilant and awake in these circumstances.*

In a review of fatigue in commercial flights [20], Rosekind et al. reported that even during 3-4 days of commercial short-haul trips, pilots had poorer sleep quality, took 12 minutes longer to fall asleep, slept about 1.2 hours less, and awoke 1.4 hours earlier. Subjective fatigue and mood were worse during layovers than before or after the trip or during flights. Fatigue increased throughout the day. The situation was worse with long-haul flights, especially eastward flights with more than 5 time zones. The second sleep period of a layover was generally the worst. Microevents indicative of sleepiness (EEG alpha or theta and/or slow eye movements) lasting 5 seconds or more occurred during the last 90 minutes of flight, even during descent and landing. Microsleep events were twice as frequent in a group of pilots respecting a flight regulation interdiction against sleep in the cockpit compared to a group who practiced planned napping [20]. Even when an observer was present, naps did occur on the flight deck of long-haul operations despite federal regulations precluding it. Observers estimate that unplanned napping during cruise can vary between 5 and 20 percent [10].

Performance decrements were objectively documented at the end of the flight compared to the beginning on night versus day flights, and during the fourth leg versus the first leg of a 12-day, 8-leg trans-Pacific trip [20]. Data were gathered from volunteer Boeing 747 crews flying eastward or westward on trans-Pacific routes, crossing 7-9 time zones [10]. This study revealed that sleep was much more disrupted after eastward night flights than after westward day flights over an equal number of time zones. In the eastward flight, sleep duration was substantially reduced on the second layover night. Age strongly affected sleep and sleepiness. It was significantly correlated with an increased number of awakenings, a higher percentage of light drowsy sleep, a lower percentage of deep sleep, and lower sleep efficiency. The average sleep loss was 1.5 hour per night, and a few subjects lost over 20 hours of sleep during the 6 days away from home. There were large inter-individual differences and carriers must assume that probably one or more crew members will be very sleepy during a substantial portion of any flight. It was also demonstrated that pilots are very poor judges of how sleepy they really are.

Other classes of employees, such as air traffic controllers (ATCs), often experience fatigue on the job, which remains a safety issue in the aviation industry [32]. Factors identified as contributors to fatigue in ATCs include lack of proper sleep, irregular shift/work schedules, workload, work environment, emotional stress, and individual factors [32]. Environment and workload are important since ATCs in low traffic density had more sleep and were more satisfied with their job than those in larger units [11]. There was also a trend for less sleep with increasing age and a reduction of performance for those over 35 years of age. Interestingly, morning types achieved more sleep during day shifts than during evening or night shifts. Twenty ATCs aged 32-59 years from Rome, the largest Italian regional air traffic control centre, participated in a study over three successive shifts – morning (7:00-13:00), afternoon (13:00-20:00), and night (20:00-7:00) [21]. The number of aircraft under control per hour was used as an index of workload. Moderate or light levels of activity were prevalent at night. Subjective and objective measures of fatigue were collected and revealed that fatigue increased on all three shifts, especially at night.

3.4 Rail Industry

In a 1992 TDC-sponsored study, Buck and Lamonde interviewed 18 locomotive engineers to prepare scenarios of critical incidents [22]. These scenarios highlight some factors contributing to fatigue in the rail industry. The engineers were asked to describe unsafe events, known as infractions of operating rules, and problems of fatigue. The consensus was that most difficult situations occurred when work began in the middle of the night (1:00-4:00). The length of the working day was not seen in itself as a problem provided that it was not excessive (fewer than 10 hours). The time of day was regarded as an important factor and several engineers found it more difficult to operate at sunrise after an overnight shift. This time is close to their circadian nadir of core body temperature and alertness. Some aspects of their working conditions presented them with problems of maintaining alertness, the most significant of which appeared to be boredom (or cognitive underload).

At the 1997 International Conference on *Managing Fatigue in Transportation* [9] it was reported that sleep disorders could be a serious contributing factor to operator fatigue, leading to performance decrements, poorer adaptation to shiftwork, and poorer recovery from sleep. Organizational factors such as work schedule unpredictability also appear to be an important cause of fatigue in rail transport. Younger locomotive engineers are at particular risk of being affected since they are on call more frequently than older colleagues with greater seniority. It was also found that more human factors were involved in accidents occurring between 2:00 and 6:00 and that higher levels of start-time variability increased the likelihood that engineers will experience fatigue. These last observations indicate the major role played by circadian rhythm disruption in performance decrements. Fatigue is often associated with speed limit infractions, failures to blow the horn for crossings, rapid throttle changes, and application of excessive train forces. Studies in train simulators revealed that when the duration of the main sleep episode was reduced from 6.1 hours to 4.6 hours, three times more performance mistakes and substantially more fuel consumption per trip were observed (for a literature review see [23]).

In summary, the following factors appear to be important contributors to fatigue in the rail industry:

- uncertainty about the time of one's next assignment
- excessive working hours
- long commutes and waiting times before beginning work
- unsatisfactory conditions for sleeping at some terminals
- decision not to rest during the day even when one could be called for duty the following night

4 CRITICAL EVALUATION OF VARIOUS WORK AND REST SCHEDULES

4.1 Trucking Industry

The Canadian Hours of Service Regulations (HOS) allow a maximum of 13 hours of driving within a 15-hour duty period before an 8-hour rest period is required. A maximum of 60 hours on-duty in 7 days or 70 hours on-duty in an 8-day period is allowed. There are no requirements for days off. A 14-day cycle provision in the Canadian HOS allows 120 hours of duty during a period of 14 consecutive days, but a 24-hour off-duty period before completing 75 hours. Before 1993, very little was known on the impact of Canadian HOS rules on sleep, recovery, and alertness/performance levels of truck drivers.

The Driver Fatigue and Alertness Study (DFAS) was the largest and most comprehensive over-the-road study in North America to date [25]. It provides extensive information on commercial motor vehicles (CMV). It represents a collaborative effort between the U.S. Federal Highway Administration (FHWA) and TDC, initiated in 1989 and pursued between 1993 and 1996. The aim of this study was to observe and measure the development and progression of driver fatigue and loss of alertness in order to develop potential countermeasures. A total of 80 male CMV drivers 25-65 years of age, with at least 1 year of experience on conventional Class 8 truck tractors participated. They were assigned to one of four conditions:

1. 10 hours day driving for 5 days
2. 10 hours driving on a rotating schedule starting 3 hours earlier each day for 5 days
3. 13 hours night driving for 4 days
4. 13 hours driving with a start at 13:00 for 4 days

Information on the amount of time spent driving during a work period, the number of consecutive days of driving, the time of day, the duration of the main sleep period, and the type of schedule was gathered. Objective measures of driving performance, such as lane tracking, relative lane markings, steering wheel movement, and driving speed and distance, were collected. An 18-minute battery of tests was administered three times per run and consisted of code substitution, a critical tracking test, and a simple response vigilance test. Video monitoring was recorded over 6-minute sections twice per hour. Physiological measures consisted of subjective alertness assessments, polysomnographic recordings during sleep and driving, body temperature, and EEG recordings. Sleep habit questionnaires and daily logs were filled. The tractor cab environment was monitored for cabin temperature, humidity, and carbon monoxide and nitrogen dioxide concentration levels.

The study revealed that the strongest and most consistent predictor of drivers' fatigue was time of day. Drowsiness was greater at night with peak levels from late evening until dawn. Time of day was a better predictor of decreased driving performance than hours of driving (time-on-task) or the cumulative number of trips made. The hours of driving were not a consistent or strong predictor of observed fatigue. Drivers' subjective self-assessments of fatigue levels were not very accurate. Huge individual differences in driver susceptibility to fatigue were observed and 14 percent of the drivers accounted for 54 percent of video-observed drowsiness episodes. There was some evidence of cumulative fatigue across successive driving days. Overall, drivers obtained about 2 hours less time in bed (the mean was 5.2 hours) and 2.5 hours less actual sleep than their reported ideal daily amount of sleep (7.2 hours). The total sleep duration per condition was 5.4 hours, 4.8 hours, 3.8 hours, and 5.1 hours respectively. However, the sleep debt may have been exacerbated by the experimental protocol. The short sleep duration observed during condition 3 might reflect the negative effect of circadian disruption. Sleep structure appeared normal on polysomnographic recordings. Video ratings were much more sensitive than waking EEG in detecting drowsiness while driving. Over 19 minutes out of the 244,667 minutes of EEG recorded while driving revealed drowsiness consistent with Stage 1 sleep. Forty percent of drivers took at least one nap during a duty cycle with clinically scorable sleep, often in response to drowsiness. There was not enough data to see whether it resulted in post-nap improvement. Large individual differences were observed in the levels of alertness and performance. A pathological number of sleep apneas were discovered in 2 of the 80 drivers but their performance was similar to others of the sample. No significant relationship was detected between driver age and fatigue.

Another study, which is an extension of the DFAS study in a subset of drivers, looked at the relationships between the prevalence of driver drowsiness observed on a trip, the length of prior principal sleep periods, and naps taken during the trip [26]. A rhythmic time-of-day variation was the strongest influence on drowsiness and accounted for about 97 percent of the variance in the drowsiness data based on video monitoring of the drivers' faces. It was followed by the length of the last main sleep episode. Half the naps were taken in the apparent absence of drowsiness and half appeared to be taken in response to a sudden increase in drowsiness. After the nap, the level of drowsiness was about half that prior to the nap but it was still substantially high. The level of drowsiness returned to the background level 3 to 5 hours after the nap. There were large within- and between-driver differences in the amount, duration, and timing of drowsiness before and after naps.

A study called the Recovery Study, also an extension of the DFAS, started in 1989 and included 55 additional trips by 25 of the 40 Canadian drivers [27]. It looked at the effect of taking 0 work day (12 hours), 1 work day (36 hours), or 2 work days (48 hours) off between the fourth and fifth trip. There was no objective evidence of driver recovery over the 36-hour off-duty period. Drivers accumulated a sleep debt, with the night-start drivers (4.4 hours per sleep period) being significantly worse than the day-start drivers (5.2 hours per sleep period). This represented a daily shortfall of 2-2.8 hours. While day-start drivers substantially reduced their average daily sleep shortfall during the 36-hour off-duty period, night-start drivers marginally increased theirs because of the short sleep on the second night off. For the sleep preceding the start of the next work cycle, the day-start drivers had their longest sleep period (6.8 hours) while the night-start drivers had their shortest one (2 hours). This may be due to the quick changeover of wake-sleep pattern from day to night in the night-start drivers. These results indicate that while the 36-hour off-duty period may be marginal for the day-start drivers, it was inadequate for the night-start drivers. It can be expected that, for drivers on consecutive night shift cycles, even a 60-hour off-duty period would not eliminate the short changeover sleep and the long wake time prior to the first night drive.

4.2 Marine Industry

From the thirteenth century until 1981, the traditional 4 hours on/4 hours off with 3 watchkeepers to cover 24 hours was in place [15]. The rationale for having a 4-hour work period was based on the extent of physical labour and exposure to extreme environmental conditions. With advances in technology and changes to task characteristics, longer shifts became possible [29]. Many watchkeepers in the Canadian Coast Guard (CCG) now operate on a two crew "layday" system using a 6 hours on/6 hours off schedule, over a 28-day period, followed by a 28-day period of rest. In 1998, this system was in use in the Maritime and Newfoundland Regions of the CCG. In the Western region, a 12 hours on/ 12 hours off schedule is employed. Typically vessels in this region patrol during daylight hours and are at anchor at night [15]. Canadian ice navigators are typically constantly on duty on the bridge while the ship is in ice-infested waters. Operators can be expected to maintain their performance for work periods of up to 12 hours duration for three to six consecutive days and even up to 18 hours duration on special occasions [15]. Current regulations impose a minimum of 6 consecutive hours of rest per 24-hour period and a minimum of 16 hours of rest per 48-hour period. The end of a rest period and the beginning of the following one must be separated by a minimum of six hours and a maximum of 18 hours. It is often felt that these regulations allow very little flexibility. Even though ice navigators are not required to follow the regulations, they seem to adhere to them most of the time [15].

A recent DFO/CCG-sponsored study compared the 4&8 to the 6&6 schedule with regard to performance, mood, and sleep. It involved four months of data collection on four East Coast ships with a total of 42 subjects [28]. Measures of performance such as reaction time and short-term memory, ratings of mood, alertness, and sleep quality, and sleep/nap diaries were collected. It was observed that, on the 4&8, crew would get one longer sleep period each day during which they slept about 54 minutes longer than those on the 6&6. However the total duration of sleep per day was not significantly different and was restricted to an average of about 330 minutes, which is inadequate to meet physiological requirements. The situation was worse for night shifts (315 minutes of sleep per day) than for day shifts (347 minutes). No significant differences were observed in the levels of performance, as measured by choice reaction time and short-term memory, or in mood levels. The authors recommended that day workers remain on the 4&8 schedule (which improved sleep length) and that night workers remain on the 6&6 schedule (better sleep for night workers). However, in the Maritimes and Newfoundland Regions, 8 hours watch would be too onerous, particularly in heavy seas, and would need to be broken into a 6-hour watch and a 2-hour period of day work. It was unclear, based on this study, how the accumulation of sleep debt over time could affect performance levels. This is of particular concern because marine watchkeepers, who work rotating shifts over extended periods, could develop disentrainment of their circadian rhythm phases, a situation thought to be experienced frequently in marine environments [29]. This is true even though ships' personnel could theoretically adapt to their daily routine faster than onshore personnel because they are shielded from potential distractions associated with urban life [14].

During the summer of 1996, crew members of two CCG icebreakers (the *Sir Wilfrid Laurier* and the *Pierre Radisson*) participated in another study [29]. The watchkeeping schedule on the *Laurier* was 12 hours on and 12 hours off (12&12), with watch rotations taking place at 12:00

and 24:00. The watchkeeping schedule on the *Radisson* was 4 hours on, 8 hours off, followed by 8 hours on and 4 hours off (4&8). Thirty-two watchkeepers between 20 and 60 years of age participated in this study. Human performance measures included cognitive performance, sleep, fatigue, and socio-psychological well-being. Other issues with potential impact on fatigue were examined, such as watch type, the scheduling of icebreaking operations, and the physiological adaptation of personnel to different watch schedules. No significant differences were observed between the 28- and 42-day crewing periods, in terms of either sleep duration or sleep quality. However, close examination of the data revealed a decrease in sleep duration from week two to six of approximately 50 minutes per day. The authors considered the buildup of sleep debt over the final two weeks to be a prime contributor to changes in crew state. This could have affected the levels of cheerfulness and calmness, which had deteriorated in weeks five and six to a point that could affect motivation and the quality of crew interaction. This could be of particular concern in non-routine situations and marine emergencies (e.g., equipment malfunctions) [29]. No significant deterioration of objective measures of performance was noted in this study. This might be due, in part, to the relatively short duration of the tasks used and would require further confirmation with longer, more sustained tasks. When the duration of icebreaking activity was extended beyond 8 days in a crewing period, it had a negative effect on crew state and induced perception of degraded mental performance [29].

The effects of an extended 42-day trip were evaluated in another field study in which members worked on a 12&12 schedule [14]. The information gathered during the study suggests that members of the 12&12 night watch do not adapt completely to a night routine. The most significant indicators of fatigue were manifested as deteriorating mood, impaired group dynamics, and impaired response to stress. It was shown that if personnel are fatigued from the onset of their crewing period, their level of fatigue is more likely to increase over the course of the crewing period. This was the case for one quarter to one third of the respondents. It was observed that the most important factors in preventing fatigue were sleep duration and sleep quality over the length of the crewing period. It was also felt that personnel on the 12&12 watch had the greatest opportunity for sleep quantity and quality, followed by personnel on the 4&8 and then those on the 6&6.

4.3 Aviation Industry

Flight Time and Flight Duty Time Limitations and Rest Periods stipulate that no private operator shall assign a flight crew member for flight time, and no flight crew member shall accept such an assignment, if the flight crew member’s total flight time exceeds:

- 1,200 hours in any 12 consecutive months
- 300 hours in any 90 consecutive days
- 120 hours in any 30 consecutive days
- 14 consecutive hours in any 24 consecutive hours
- 15 consecutive hours in any 24 consecutive hours if (i) the total flight time in the previous 30 consecutive days does not exceed 70 hours or (ii) the rest period prior to the flight is at least 24 hours

Flight duty time may be extended beyond the maximum flight duty times as a result of unforeseen operational circumstances. A private operator shall provide each flight crew member at least one period of 36 consecutive hours free from duty within each 7 consecutive days; or at least one period of 3 consecutive calendar days within each 17 consecutive days.

The current collective agreement of ATCs stipulates that:

- 36 hours, averaged over a one-year period, should constitute the work week
- shifts should not be less than six hours or more than eleven hours
- the commencement of a shift should not be scheduled within ten hours of the completion of the employee's previous shift
- shift cycles should comprise seventeen days of work and eleven days of rest over a 28-day period
- shifts should be scheduled in a succession of four to six days of work
- days of rest should be consecutive and not less than three days

To our knowledge, many of the studies looking at the effects of various work/rest schedules in the aviation industry have involved groups of ATCs (for a review see [32]). In one such study [30], the effects of a 10-hour 4-day (2 afternoons-2 mornings) rotating schedule were compared with those of an 8-hour 2-2-1 schedule (2 afternoons-2 mornings-1 night). A total of 52 ATCs with a mean age of 37.9 years participated. Measures of performance and alertness, and daily logs on sleep, mood, and somatic complaints were obtained. There was no evidence of lower performance on the battery of tests within or across work days on the 10-hour versus the 8-hour shifts. However, the jump between shifts was more drastic on the 8-hour 2-2-1 and more progressive on the 10-hour schedule. The daily duration of sleep got progressively shorter on the 10-hour shifts to approximate 5.75 hours prior to day 4. On the 8-hour schedule, sleep duration was drastically reduced prior to the last shift (about 3.75 hours). This phenomenon was attributed in part to the tendency to take only a brief nap prior to a night shift. Slower reaction times and greater errors occurred during night shifts. In the 2-2-1 schedule, a relatively normal amount of sleep and family schedule was observed. The percentage of younger controllers preferring the 2-2-1 appears higher than that of older ones.

A 1994 TDC report describes a national survey in which 921 ATCs answered 114 questions relating to their job characteristics, sleep, and coping strategies [11]. An increase in the occurrence of having fallen asleep while driving to or from work was reported by ATCs when they worked the night shift (27 percent) compared to day shift (16 percent). This risk increased to 32 percent if they worked five consecutive nights. The amount of overtime was associated with health complaints such as difficulty waking, feeling moody and grumpy, feeling tired and drained, shortness of breath, heart racing or skipping, stomach aches, and dizziness. Fifty percent of ATCs obtained 6 hours sleep on the day shifts, eight hours or more on the evening shifts, and five hours on the midnight shifts. During the quick-change evening-to-day shift, many ATCs got only 4-5 hours of sleep per night and sleep was of poor quality due to the anticipation of the alarm clock. It was also noted that ATCs tended to overestimate their total sleep time. One polysomnographic recording in two subjects revealed that sleep efficiency drops to 69.7 percent after the fourth night shift, with an absence of REM sleep and a drastic reduction of slow wave sleep (3.5 minutes of stage 3 and no stage 4). A significant number of ATCs (46 percent) felt that day shifts had a larger negative impact on alertness due to the early start. It is worth mentioning that many of these day shifts, such as at the Ontario Air Control Centre, start before 6:00. Several ATCs (35 percent) considered the night shift to be the worst, but few ATCs worked the night shift in the sample interviewed. The lack of breaks was seen as making the night shift more difficult. A noticeable drop in energy level and ability to cope was observed at 14:00-15:00 and 4:00-6:00. Finally, ATCs with 1-2 quick shift changes per week (i.e., less than 12 hours off between shifts) had less sleep on all shifts and were significantly less fit, less healthy, and reported more illness (headaches, stomach aches, lapses in attention).

Disturbed sleep is perhaps the most dramatic effect of shift work on any schedule and is associated with a drop in attention and performance. Many prefer delaying (clockwise) shift systems to advancing ones (for a review see [11]). Counterclockwise systems have quick turn-arounds at each shift resulting in shortened sleep periods and increased fatigue. The adaptation to clockwise could be easier because of three factors:

- the endogenous circadian system has a natural tendency to delay each day [92]
- the shape of the phase response curve to light implies that late evening exposure to light has a tendency to delay the circadian clock even further [93-95]
- the human circadian system is much more sensitive to light than initially suspected, such that even ordinary indoor room lights exert a significant phase shift [96].

Some suggest that regularity is more important than the total time asleep. Rapidly rotating shifts involve working no more than two to three consecutive days on the same shift.

In a TDC-sponsored study [31], the effects of three different shift schedules on ATCs were evaluated. These shifts consisted of straight days; counterclockwise, rapidly rotating 2-2-1 (2 afternoons-2 morning-1 night); and counterclockwise, rapidly rotating 2-1-2 (2 afternoons-1 midday- 2 early mornings). The morning shifts began at 6:00 to 8:00; the midday shifts began at 8:00 to 13:00; the afternoon shifts began at 13:00 to 16:00; and the night shifts began after 21:00. Shifts were 8-9 hours long. A total of 24 ATCs (18 men, 6 women, 8/group) participated. They kept daily log books and filled out subjective assessments of sleepiness for 2 weeks on a 2-2-1, a 2-1-2, or a straight day schedule (8/group). Early morning shifts were associated with reduced total sleep time (6 hours/night). This may be because ATCs do not go to sleep earlier at night before working an early day shift and must often commute long distances to go to work [32]. Early day shift performance is decreased and can lead to reduced operational safety at the time of the morning peak of activity. The 2-1-2 schedule had the greater sleep time over the course of the work week. At the start of this schedule, sleep periods were 7.5-8 hours long and declined to 6 hours before the early mornings. This schedule had no night shift and 12 hours off between shifts. It also compressed the work week, with 8 additional hours off between work weeks. The 2-2-1 showed a characteristic decline from 8 hours during the afternoons to 5 hours for the mornings to 2.4 hours for the night shifts. It had 8 hours off between shifts. There was no difference in sleepiness ratings due to the schedule type, and all ATCs were sleepier at the end of the shift and on the last day of the week. However, there were more extreme ratings of sleepiness after the night shift on the 2-2-1 and less during the 2-1-2. It was found that overtime interfered more with social activities than the shift cycle did. Overall, ATCs tend to prefer counterclockwise rotations because of the opportunity to get extended weekends. Unfortunately, older ATCs often report greater difficulties adjusting to these schedules and more research is needed to clarify this often emotional issue of work scheduling [32].

4.4 Rail Industry

The present Canadian work rules for the rail industry allow a maximum of 18 hours per day of duty time. In comparison, the American regulations allow a maximum of 12 hours per day of duty time and a minimum of 8 hours rest per day [23]. It was found that U.S. railroads were essentially complying with the Hours of Service Act and that 99.4 percent of the engineers were given at least 10 hours off duty after a work period of 12 hours or more. It was thought that reducing the shift from 12 hours to 10 hours would increase the variability in the work schedules with a greater negative impact on alertness levels. So far, very few studies have compared the effects of different work schedules on measures of alertness in rail operations. The effects of fatigue on the train handling performance and vigilance of four certified train service locomotive engineers were measured while they operated the Research and Locomotive Evaluator/Simulator (RALES) [33]. The RALES allows evaluation of various aspects of a train's status as frequently as 0.5 second intervals. The engineers operated on an hourly cycle of 12 work-12 rest-8 work as a "normal cycle" followed by an hourly cycle of 12 work-8 rest-8 work the following week as a "fatigue cycle". Deterioration of performance occurred regardless of the work schedule and was coupled with the irregular sleep/work patterns. The engineers were observed to doze or nod off while operating the train. Speed limit infractions, failure to blow the horn for crossings, rapid throttle changes, and excessive train forces were observed as a result of fatigue. Following the 12-hour period, the engineers were allowed to rest and were not disturbed until 10 hours later. Sleep/wake diaries were obtained. Overall, no differences were observed between the schedules. A history of adequate sleep was observed based on the sleep/wake diaries. However, engineers of both groups did have disrupted sleep patterns that increased the risk of attention lapses during periods in which relatively low levels of operational performance or motor behaviour were required. Since the study did not take place during the most critical time of day, i.e., at dawn, the contributing role of circadian rhythms could not be properly assessed. Further studies are thus needed to compare various work and rest schedules in the rail operations.

5 CRITICAL EVALUATION OF DIFFERENT COUNTERMEASURES

5.1 Trucking Industry

An expert panel on driver fatigue and sleepiness recently concluded no “driving strategy” could get drowsy drivers safely to their destination and that such strategies were no substitute for good sleep habits. [4]. The panel was unanimous that napping before a long drive may help and has the greatest effect on performance levels up to several hours after the nap.

Unlike situations with alcohol-related crashes, no test is currently available to quantify the levels of sleepiness at the crash site. Public education about specific behaviours that help avoid becoming drowsy while driving should be pursued. Strategies should include the recognition of drowsiness and interruption of driving to take a short 15-20 minute nap or two cups of coffee. Authors mentioned that it was uncertain whether driver training reduces accidents [34].

Other types of strategies designed to increase the level of stimulation in the work situation could be proposed (light physical activity, controlled noise, interaction with workmates, cold/fresh air) [9]. These countermeasures seem effective only while the stimulation is on and their effectiveness is short-lived. So far, there is no strong evidence for the effectiveness of commonly accepted remedial approaches such as brief exercise, listening to the car radio, or opening the car windows. The effectiveness of low doses of caffeine as a measure to improve alertness in sleepy people has been demonstrated [4]. The minimum dose needed can be obtained in two cups of coffee. Limited evidence suggests that physical discomfort (sitting in an uncomfortable position and shivering or sweating) may improve alertness temporarily [4]. Increased physical activity such as walking around appears to be the favorite countermeasure of fatigued individuals. But very heavy physical work should be avoided because it is followed by aftereffects on alertness, resulting in a more rapid onset of sleepiness. The ingestion of sugar could help in alleviating drowsiness, whereas heavy food could increase drowsiness levels. However, the alerting effects of food intake are speculative and research is limited. Considering the arousal effects of sudden stimuli, high frequency noise could have performance-enhancing effects, whereas low-frequency noise and monotonous noise can cause drowsiness. Åkerstedt reported the results of a study in which a sudden reduction of the ambient temperature for 4-8 minutes (activated by the driver who perceived a drop in alertness) was effective in improving vigilance [9]. Poor ventilation of the work environment should also be addressed since it could be a cause of drowsiness. Finally it was proposed that increased lighting could have a direct stimulating effect independent of its circadian phase-shifting effect. No current data linking bright light treatment to changes in rates of motor vehicle crashes is available. Further research is needed to clarify these issues.

The organization of work and rest is imperative to reduce drowsiness levels and the risk of fatigue-related crashes. Suggested measures to help drivers with their first trip could be: limiting the number of hours worked from 00:00-6:00; providing night-start drivers with additional time off daily; providing good sleeping facilities and nominal financial incentives; and increasing the off-duty period for drivers changing from day to night shifts [27]. It is generally agreed that two full nights of sleep are required for recovery from acute and cumulative fatigue over an extended period of time [35]. These measures will be of limited value without good education and incentive programs. Even when given substantially more sleep opportunity, drivers do not necessarily use it to obtain their reported ideal sleep. Health management systems should be developed and should include the assessment of sleep disorders or other fatigue-related conditions and health problems, e.g., diabetes [36].

Some Australian states regulate truck driving hours while others, such as Western Australia (WA), the country's largest state, do not. The WA Department of Transport concluded that there is no evidence that prescriptive HOS manage fatigue better than WA's existing practice and found it more important to review the overall scheduling frame than to control the hours worked within a trip [9,37,38]. As an alternative to prescribed driving hours, Queensland introduced a 5-year public policy experiment in March 1994. Stemming from that is the Fatigue Management Scheme (FMS), a statute containing performance-based standards that permit a degree of flexibility [38]. Failure to demonstrate adequate fatigue management practices results in withdrawal of HOS exemptions. The HOS requirements are a maximum of 12 hours driving/day; a minimum of 9 cumulative hours of rest in any 24 hours, of which 6 hours must be consecutive; a maximum of 5 consecutive hours of driving prior to taking at least a 30-minute break; a maximum of 72 hours of driving/7 days; and driver log book completion. Some strategies used by unregulated drivers in Australia were: pull over when tired (81.7 percent); drink caffeinated beverages (68.5 percent); obtain a good night's sleep before departure (62.4 percent); sleep regular hours and at predictable intervals (32.1 percent) [9]. Some of the countermeasures proposed are to transfer to lighter duties to allow sleep at home; revise trip schedules to permit breaks; revise pick up and delivery times if possible; be more tolerant of discretionary rest; and avoid night driving. More information is needed to carefully assess the impact of HOS or HOS exemption incentive programs. Log books also seem to be ineffective in ensuring compliance with driving hours [34] and are routinely falsified [3].

Canada has also been examining "alternative compliance" for managing fatigue rather than regulating it. But this approach must be recognized by all relevant jurisdictions [9]. Transport Canada considers flexibility is needed for interprovincial carriers and has established a pilot project to test a Canadian Fatigue Management Program (FMP). Work/rest scheduling may be supported by the use of sleep-history monitoring technologies, and may be modelled on the current Fatigue Management Programs for truck drivers in Australia [36] and in Canada [39,97]. Incentive programs for accident-free performance seem to be the most promising in affecting people's motivation towards safety [39]. Accident reductions of at least 80 percent have been reported with the use of such programs [39]. Moreover, the cost of bonuses and program administration is considerably smaller than the savings due to accident reduction. Indeed, some companies interviewed in the context of a pilot study in Canada reported a three to one benefit/cost ratio for their incentive programs [39].

Fatigue management programs that would use behaviour-based safety principles have been proposed [40]. These are designed to encourage self-management rather than the implementation of procedures. In self-management, the effect of performance feedback is important to allow for a positive change in safety behaviour. It is proposed that feedback data, available through performance measurement technologies, could generate valuable data for the driver, company management, and regulatory agencies. Various levels of feedback could be provided, without the identification of any individual driver.

In recent years, great interest has been invested in technology to manage fatigue-related performance impairment in commercial motor vehicle operations [2]. Technological devices were recently discussed at an expert panel on driver fatigue and sleepiness and concerns were raised by panelists:

> *An inherent deficiency in all types of alerting devices is that many people continue to drive even when they know they are drowsy and fighting to stay awake.*

An example of a simple and useful device is the SNAP (Sonic Nap Alert Pattern), designed by the Pennsylvania Turnpike to produce enough vibration and sound to be perceptible in a truck cab and yet not too severe for cars or motorcycles. It was shown that use of the SNAP can reduce drift-off road accidents by 65-70 percent. Panelists agreed that shoulder rumble strips placed on high-speed, controlled-access, rural roads could reduce drive-off-the-road crashes by 30-50 percent. However, drivers should see them only as a warning that they should take some countermeasure such as a nap, fresh air, coffee, a walk or change drivers.

Technology must be acceptable to the driver and unobtrusive. It must be validated and normative and quantitative data must be obtained. It should be easy to learn, to use, and to maintain, including the calibration steps. Technology could be used as a continuous “fuel gauge” display of alertness or “alertometer” that informs the driver of his or her vigilance level. However, it may encourage drivers to continue driving, whereas a single threshold alarm would communicate that falling asleep at the wheel is imminent. Loss of driver alertness is almost always preceded by a period of measurable performance decrements and associated psychophysiological signs [6]. Alertness detection technology could ultimately be housed in vehicle cabs of commercial and non-commercial vehicles. For economic and statistical reasons, the U.S. Federal Motor Carrier Safety Regulations focus primarily on combination-unit trucks (CUTs) for advanced vehicle-based technologies [98]. CUTs are involved in more expensive accidents, estimated at U.S. $765M annually [24]. Incentives could be implemented to encourage the proper use of such technological devices. This is particularly important, since even if drivers are aware of their deteriorating conditions, they are often motivated or under pressure to keep driving [6]. Regulatory incentives offered by the government to industry and/or incentives offered by industry to the drivers (e.g., monetary or other rewards) could be implemented [24].

Eye closure measures, and particularly PERCLOS, were shown to be well correlated with other drowsiness indicators. Slow eye closure is physiologically based. When the magnitude is sufficient individuals can no longer gather visual information and performance degradation is likely to occur. PERCLOS is defined as the percentage of time that the eyes are 80-100 percent closed. It assumes that only slow eye closures are tracked and it excludes blinks. PERCLOS is strongly correlated with lane-keeping measures of performance such as lane excursion and lane deviation, which are considered to be the most reliable measures of driving performance. It is also correlated with several EEG measures and with subjects’ self rating of drowsiness. PERCLOS is highly correlated with PVT, a performance task sensitive to drowsiness. Six technologies were tested against PVT in a 42-hour sleep deprivation study in 14 healthy men. Nearly all of the technologies showed potential for detection of drowsiness-induced hypovigilance by accurately predicting lapses. However one major problem is the high inter-subject variability. Only PERCLOS correlated highly with PVT lapses both within and between subjects. There are marked individual differences in the occurrence of specific oculometric signs of impaired ability and it is assumed that a single measure may not work for everyone. Moreover, tests done in driving simulators showed that driving performance was deteriorating before eye closures of substantial magnitude occurred. When PERCLOS measures are combined with direct performance measurements, accuracy improves.

Fatigue management strategies based on wrist/activity monitor and sleep/wakefulness models have also been proposed. Alternative work schedules, different from HOS regulations, may come closer to a natural circadian sleep-wake cycle. One such pilot project makes use of an actigraph to inform drivers when they need more sleep, as well as a sleep management model that provides readiness-to-go feedback. Such initiatives appear very promising in integrating scientific knowledge into work/rest scheduling practices.

The development of a crash avoidance Intelligent Transportation System (ITS) started in the early nineties at Virginia Polytechnic Institute and State University [6]. This system is designed to be a driver status warning system as opposed to a warning of a specific imminent collision threat [6]. A program called “Modeling of driver performance under various work/rest cycles” (summarized in [5]) was initiated at the Walter Reed Army Institute of Research. The aim of this program is to gather laboratory data on the effects of different sleep/wake cycles on vigilance and performance. These data are then used to validate the Sleep Performance Prediction Model (SPM), a mathematical model for performance prediction. Finally, actigraphy data on CMV drivers in real-world operations are obtained to assess the impact on performance of various work/rest schedules and to validate the model. It is expected that the SPM will eventually reach the level of sophistication necessary to accurately predict performance scores (e.g., PVT) and PERCLOS scores based on the sleep/wake history. The possibility of developing dashboard-mounted detection systems has been explored. A successful system should have a very high detection accuracy and a low false alarm rate [6].

Intelligent transportation systems (ITS) could be designed to provide continuous in-vehicle driver monitoring, consisting of a simple continuous indicator display of driver alertness level (“alertometer”) that would be used in a manner analogous to current use of speedometers [24]. Such systems could incorporate an intervention algorithm that would send advisory messages, warning signals, or an alerting stimulus such as blasts of cool air, seat vibration, release of stimulating aromas, secondary verbal tasks, or act as a “lane minder” that is, have an in-vehicle rumble strip function [6]. The lane minder system could function better than a roadway rumble strip since it could anticipate an imminent roadway departure based on vehicle trajectory and physiological signs of drowsiness. A useful device should be able to detect drowsiness before a driver is in immediate danger of a crash. It should be able to prevent road departures, the main cause of drowsy driver crashes [6]. It must be reliable, acceptable to drivers and managers, affordable, and user-friendly [24]. Such ITS and crash prevention algorithms are being tested on an experimental basis [5].

Fitness-for-Duty/Readiness-to-Perform (FFD/RTP) testing is in its infancy and no clear validation criteria have been set [41]. FFD/RTP testing relies on brief, narrow, simple behavioural testing. At this stage no measures validly assess the state of job preparedness. We must remain critical regarding how FFD/RTP is defined and identify proper criteria based on high quality predictive validity studies.

5.2 Marine Industry

Various countermeasures have been suggested to improve fatigue management in the marine transportation industry. These can be grouped into four main categories [14,29]:

- **Selection criteria could be considered**. Watchkeepers could be selected according to their capacity to adapt to irregular schedules.

- **Continued evaluation of various work/rest schedule and vigilance testing is suggested**. This is important during extended crewing, especially if 12&12 watches are implemented. These types of schedules should be implemented in a systematic manner.

- **Organization of workload and human resources is very important**. Crew should be provided with opportunities for strategic rest periods to take naps such that they can achieve maximal sleep. Crew preferences should also be considered in the scheduling of the work. Older crew members could be assigned to day watches. If icebreaking is late in the duty cycle, additional rest and extra precautions are required. Whenever feasible, and especially if recovery from sleep debt is needed, crew should be given the opportunity for adequate sleep for at least two nights. Commanding officers should provide relief to watchkeepers to help recovery when workload is high. Sufficient time off needs to be provided between successive 42-day cycles. The work schedule should consider not only the hours of work, but also other factors affecting fatigue, such as vessel tasking, weather conditions, circadian factors, and the amount of sleep obtained. Overtime should be kept to an operationally viable minimum.

- **Implementation of a training program on fatigue management is primordial**. This program should inform crew members on the physiology of sleep and circadian rhythms. They should also be encouraged to maintain the same sleep/wake pattern as when on leave. Providing crew with information about coping strategies will help them deal more effectively with extended crewing periods.

To these countermeasures, those already described in the other modes of transportation could be added. For instance, technologies could be designed and tailored to the marine industry to document alertness and performance decrements as they develop. These could serve as “alertometers” and/or be incorporated into a device to counteract fatigue. These are avenues for future research and will certainly benefit from technological advances made in other modes of transportation, such as the trucking industry, where greater economic impacts are possible. This mode of transportation would benefit from in-laboratory studies, in addition to field studies, because of the settings in which marine personnel must operate. More research is needed to improve the adaptation of human beings to the unconventional and often split schedules used in marine operations.

5.3 Aviation Industry

Strategies used by ATCs to improve their adaptation to shift work include regular exercise and good diet, attempts to get an adequate amount of sleep, and attempts to maintain good health [11]. Coping strategies such as smoking, drinking coffee, and taking sleeping pills or alcohol negatively correlated with good health. Recommendations were made to educate ATCs, their managers, and families on sleep strategies and hygiene. Overtime should be avoided immediately after consecutive night shifts, double quick-changes, or any compressed schedule. A pilot project of formalized napping, or at least the opportunity to break, could be implemented [42]. Optimal scheduling with recovery time that would take into account the amount of sleep loss should be implemented [16].

These same recommendations could apply to air crew. Strategic naps during the cruise portion of the flight can be used effectively to promote the performance and alertness of pilots. These should take into account the two potential negative effects of naps, namely sleep inertia (which may last up to an hour) and detrimental effects on subsequent sleep periods [9]. Study of planned rest periods of 20-40 minutes in long-haul flight operations has demonstrated the effectiveness of in-flight naps to improve alertness of the crew when they begin the descent phase of their flight, especially on the last leg of a crew duty cycle [43]. A study of 10 volunteer Boeing 747 three-member crews on regularly scheduled transpacific flights has demonstrated that, when allowed, pilots are able to fall asleep 93 percent of the time, while seated at their crew stations. They slept for an average of about 25 minutes. Most flights had about a 3-hour window during which there were no meals or other activities and the crew could take turns resting [43]. Cockpit rest should be viewed as a safety valve and appropriate flight and duty time should be revisited.

Extension of this study, including a 40-minute rest period followed by a 20-minute recovery period, brought similar results [19]. Attention should also be paid to on-board sleep facilities; scheduling should be more appropriate for circadian physiology; and education programs on the effects of napping, circadian rhythms, diet, exercise, and coffee for personnel on long-duration operations should be implemented [18]. The flight crew scheduling should take into account the time of departure, the number of time zones, and the impact of a series of flights within a trip (especially important for a two-crew trip of 9- or 10-hour duration). The concept of “anchor sleep” could also be incorporated into work schedule planning. This concept is based on the timing of sleep at home and serves to adapt the timing of the sleep period in the new time zone. It is proposed that if crew members cannot get at least 50 percent of their sleep during the anchor period, they should not be scheduled to fly a second segment after that sleep period [10].

Other countermeasures such as the use of diet, exogenous melatonin [44,45], or bright light exposure are still at the investigation stage. Issues surrounding regulating their use in an operationally complex environment still require clarification. There are no valid scientific data to support one diet rather than another, but proper nutrition and stable life style habits are recommended. For example, the effectiveness of a popular “jet lag diet” (high protein breakfast, high carbohydrate dinner, scheduled caffeine consumption) has been tested [99]. No significant changes with diet were observed in the adaptation to phase shift of the sleep-wake schedule.

Several field studies have proposed the use of exogenous melatonin, a hormone naturally secreted at night by the pineal gland, to induce rapid adaptation to jet lag [44-46,79,100-103] but contradictory results have been reported [47]. These data are based mainly on the publication of a phase response curve to melatonin [104], which is opposite to that of light. However, the magnitude of melatonin-induced phase shifts is much smaller than those induced by bright light exposure [93-95]. Unfortunately, in most studies, exposure to sunlight or room light was not carefully controlled and the possibility that melatonin might have induced adaptation by a sleep-inducing effect is not excluded. There is reasonable clinical data to support a beneficial effect of exogenous melatonin on sleep [105-107]. The optimal dose of melatonin is still unclear since no dose-dependent experiments have been systematically carried out [105]. The sleep-promoting effect of exogenous melatonin is more pronounced during the day than at night [112-114] or when endogenous melatonin is deficient [113,115,116]. Initial studies used rather high doses (up to 240 mg) of oral melatonin that resulted in supraphysiological levels [105,117]. Doses of 0.3-1.0 mg for the normal release formulation and of 2 mg for the slow release formulation are closer to the physiological range [107,108,118,119]. Peak levels are observed 20-60 minutes following oral ingestion [107,108,120]. Improvement of sleep quality and sleep duration has been reported with 0.3-1.0 mg without consistent change in subjective sleep assessment [107]. Slow-release melatonin has been successfully used at night to improve sleep quality in elderly insomniac patients with documented melatonin deficiencies [112,113]. This formulation allows for the maintenance of effective melatonin concentrations throughout the night as opposed to fast release formulations. Furthermore, it improved sleep maintenance in these patients. The mechanisms by which melatonin promotes sleep are unclear. The possibility that it is mediated by a lowering of the core body temperature has been suggested [121,122]. The induction of sleep spindles on the EEG spectrum following melatonin ingestion also suggests a direct hypnotic effect similar to that of benzodiazepines [124] and an interaction with the GABA-benzodiazepine receptor has been proposed. Anecdotal reports of side effects in the literature include headaches, sedation, restlessness, confusion, nausea, tachycardia, and itchiness [105,112,119]. However, these may be caused by impure preparations. So far, it is unclear whether exogenous melatonin could have any advantage over other classes of hypnotics and its long-term effects are undocumented.

Even before the publication of the phase response curves to light in humans [93-95], Daan and Levy suggested a strategy of adaptation to jet lag based on the time of exposure to bright light [48]. Since then evidence has revealed that a judicious schedule of exposure to light and darkness is important to rapidly adapt to transmeridian travel and shift work [48,50,81]. For instance, transmeridian travellers who expose themselves to sunlight upon arrival would adapt more rapidly than those who stay indoors [49]. Controlled experiments in the laboratory have shown that exposure to bright light (about 10,000 lux) is able to improve reentrainment of several endogenous circadian rhythms to an inverted sleep/wake cycle [51,52,125]. On the basis of these observations, travellers were advised to expose themselves to sunlight in the arrival country as soon as possible to hasten adaptation to the new time zone. However, to our knowledge no study has systematically investigated how exposure to lower illuminance levels can affect adaptation to jet lag. This is particularly important since, in modern society, urban dwellers are generally exposed to light levels of low to moderate intensity [126,127]. Moreover, recent pieces of evidence suggest that light exposure of an intensity similar to that produced by standard indoor lamps can significantly change the phase of the endogenous circadian pacemaker [96,128] as well as the magnitude and direction of a bright light induced phase shift [93].

It is clear that work-scheduling practice in the aviation industry should take into account not only episodic exposure to bright sunlight but also the overall pattern of light and darkness exposure throughout days and nights. Even light of ordinary indoor illuminance level should be considered, since it can induce significant phase advance shifts of the endogenous circadian rhythms of core body temperature, plasma melatonin, and plasma cortisol. We are currently investigating the effect of exposure to ordinary levels of light in the adaptation to a simulated Montreal to London voyage in healthy young subjects. Preliminary results support our initial predictions and indicate that the schedule of exposure to lower light levels can substantially affect reentrainment to a shifted sleep-wake cycle. These studies have important implications for the treatment of maladaptation to jet lag and shift work and could be incorporated into work scheduling practices for various modes of transportation much more easily than exposure to bright light.

5.4 Rail Industry

Overall, the transit industry has no standardized multimodal regulations relevant to the issues of fatigue (commuter rail, bus, rail transit, rapid transit, and heavy rail/light rail). Panelists of the 1997 International Conference on Managing Fatigue in Transportation [9] were unanimous about the advantages of obtaining a good solid sleep period before a trip and using nap strategies en route. Strategic naps can be used effectively to promote performance and alertness in an operational setting. It must take into account the two potential negative effects of naps: sleep inertia and effects on subsequent sleep periods. Panelists also agreed about the short-term use of other fatigue countermeasures, including exercise bouts, caffeinated drinks, sitting in unusual postures, opening the window for cold fresh air. The latest safety report of the U.S. National Transportation Safety Board (NTSB) [3] mentioned the need for quality sleeping areas while away from home, pointing out that many hotels do not have rooms that are adequate for daytime sleeping. The NTSB believes cooperative efforts are needed to reduce the element of unpredictability in work schedules in the railroad industry.

In the early nineties, Transport Canada proposed regulations that would limit a locomotive engineer’s work to 12 hours per day. [53]. However, both the railroads and the railroad union felt this would not solve all fatigue-related issues. TDC mandated the railroad industry to develop policies and procedures to deal with crew rest and fatigue problems. A task force was formed with Canadian National (CN), Canadian Pacific (CP), Via Rail, The Brotherhood of Locomotive Engineers, and a private contractor to create what is known as CANALERT 1995. In this project, time pool scheduling was offered with three types of time pool based on starting time of assignment at the home terminal. These time pools were referred to as the “larks”, the “owls”, and the “cats” for times of assignment of 5:00-15:00, 13:00-23:00, and 21:00-7:00, respectively.

These time pools improved the regularity and predictability of the work scheduling. Redesigned rest facilities had protected zones for rest that took into account the travel time to and from home, and a napping strategy was implemented. Employees were also assigned to regular work schedules (one day on, one day off; with a minimum of 3 days off per 28-day period). A napping policy was implemented. Locomotive engineers could take a 20-minute nap when they arrived at a siding where a delay was expected. They would then notify Railway Traffic Control and switch to a special radio frequency [53]. Terminal napping facilities with comfortable chairs were established. A 4-hour training program for engineers and their families was offered. Altogether, 40 engineers participated in a 6-month study and 80 percent indicated that the time pool was reasonably or extremely effective at increasing alertness and decreasing fatigue. About 85 percent felt it improved their family and social life. However, there were no significant improvements in objective measures of vigilance, EEG, ocular motor tests, or sleep duration and quality. “Power napping” was found to be non-disruptive to railway operations and was judged to be effective for enhancing alertness in most engineers [53]. Since the release of the CANALERT report in May 1996, CN has implemented an Alertness Assurance Program. The CANALERT project was continued by CP at their Calgary Terminal. The program had more sophisticated scheduling that would maximize the likelihood that a person gets several hours of rest during critical circadian phases. In addition, engineers and conductors who are on the circadian pools may request demand naps or opportunity naps lasting 25-35 minutes each.

Similar initiatives have been launched in several locations in Canada and the U.S. One such project was the Conrail Initiative for Mental and Physical Alertness (IMPAC) (for a review see [23]). This program provides lifestyle training for employees and their families, screening for sleep disorders, improved work/rest schedules, installation of crew rest facilities at terminals, and controlled rest periods and naps. The Conrail project resulted in significant improvement of subjective alertness and a significant increase in the percentage of engineers sleeping 6 or more hours per day. About 54 percent of them used napping. Health improved, with a lowering in blood pressure, an increase in exercise, and a decrease in caffeine consumption. This led to a reduction in operating costs. Despite all these initiatives, few railroads have adopted any of the fatigue countermeasures on a system-wide basis. A survey among Canadian Engineering Services employees revealed that about 50 percent considered that fatigue was still a problem and suggested a series of countermeasures:

- improved schedules with reduction of night work
- boarding-bunk car improvement
- lifestyle training and education
- improvement in commuting home
- potential strategic napping

The testing of some technological approaches has also begun. Technologies such as the Mobile Operator Monitor (MOM), the Positive Train Separation, the Enhanced Proximity Warning Systems, and the Positive Signal comparator were proposed [23]. The MOM alerts the individual through the sounding of an alarm that there is potential for sleeping. The device operates by tracking eye blinks. The Positive Train Separation and the Enhanced Proximity Warning Systems include an enhanced crew alertness system that monitors train position and performance relative to other trains. It establishes speed limits as well as safe braking distances using an on-board computer. The Positive Signal comparator works with a GPS overlay. To our knowledge, there are no reliable and valid data on the reliability of these devices but it certainly represents an area worthy of future investigation. Panelists of the 1997 International Conference on Managing Fatigue in Transportation [9] thought that installing technological monitoring devices in workstations would be unpopular because they can be viewed as impositions of management control. They advise that these devices be used only to provide feedback.

6 RECOMMENDATIONS AND FUTURE RESEARCH

6.1 Behaviour-based approach

The results of laboratory and field studies should translate into practical recommendations to improve alertness in the transport industry. Most countermeasures could be applicable to any mode of transportation, since the physiological basis of operator fatigue is the same regardless of whether fatigue occurred while travelling on the ocean, the railroads, the highways, or in the air. Cooperative efforts are needed at several levels to promote a fast and valuable transfer of knowledge to real-life situations. Efforts should certainly be initiated at a behaviour-based level to:

- provide comprehensive education programs regarding shift work, work and rest schedules, and proper regimens of health, diet, and rest
- implement fatigue management programs in all transportation industries to educate drivers, navigators, pilots, ATCs, family members, unions, management, governmental agencies, and politicians on the safety issues related to fatigue and sleep loss
- encourage drivers, navigators, watchkeepers, locomotive engineers, air crews, ATCs, and support staff to get enough sleep prior to their shifts
- encourage incentive programs for accident-free performance
- promote a behaviour-based safety approach and self-management with performance feedback through measurement technologies
- screen for sleep disorders or other fatigue-related and health conditions
- consider crew preference and age in work scheduling

6.2 Organization of work and rest schedules

It is clear that the current HOS regulations are based on outdated rules that do not optimize safety, productivity, or quality of life [24]. So far, regulatory bodies worldwide neglect to consider circadian factors in the design of HOS for the transportation industry. Regulations should be reviewed to take into account the physiological basis of operator fatigue, namely the disruption of the sleep/wake cycle and of the endogenous circadian system. For instance, an off-duty of 8 hours does not appear to provide sufficient opportunity to recover, since it is generally associated with less than 5 hours of sleep. A reform of prescriptive HOS rules that would allow enough flexibility to regulate operator fatigue rather than duty time is advised.

The following recommendations would help to incorporate the latest research on sleep and circadian rhythms into work scheduling:

- consider all duties performed for the transport industry in the duty time
- limit or avoid 12 hour shifts
- schedule duty shifts to be between six and ten hours
- limit or avoid counterclockwise rotating schedules
- limit or avoid split sleep patterns

- improve the regularity of duty periods on reserve and on-call assignments and reduce the element of unpredictability
- recognize the cumulative and detrimental impact of multiple departures and arrivals by progressively increasing the duration of rest periods
- promote a good solid night of sleep prior to a trip
- encourage preventive napping prior to a night shift or a long trip
- encourage strategic napping en route, especially during night shift or on the cruise portion of long-haul flight operations
- limit night shifts to a succession of 2 to 3 consecutive nights
- avoid 12-hour night shifts
- avoid extending night shifts past 8:00
- avoid starting day shift prior to 7:00
- encourage rest period after about 4 to 5 hours of operation
- provide a minimum of two full days of rest after an extended duty period, especially if it involves night work
- protect break periods by providing a 30-minute break after 4 to 5 hours of operations
- provide a minimum of 9 hours of rest between two consecutive shifts
- increase the duration of rest periods during intense work load (e.g., ice breaking)
- limit overtime to an operationally viable minimum
- promote the “anchor sleep” approach when crossing several time zones and returning home shortly

6.3 Revision of the work environment

- improve the cabin environment (ventilation, temperature, noise, vibration)
- increase the number of rest areas nationwide
- increase the visual signals and number of rumble strips on highways
- improve sleeping facilities
- provide adequate areas for strategic napping on board ships, aircraft, trains, trucks
- limit the use of the sleeper berth to a maximum of 2 consecutive nights because it promotes split sleeping
- improve the quality of sleeping areas away from home
- negotiate special arrangements with hotels such that air crew can recuperate from jet lag and night work
- improve commuting home arrangements

6.4 Future research

- Further studies are needed to develop reliable, practical, and cost-effective technologies to assess fitness for duty/readiness to perform, and to detect and counteract drowsiness in operators of a vehicle, ship, train, or aircraft
- More studies are needed to clarify the minimal duration of a rest period to recover from a cumulative sleep debt

- Combined laboratory and field studies are needed to better assess the adjustment of the endogenous circadian system in the transport industry. It is clear that circadian factors play a predominant role in the adaptation to shift work and sustained operations. In most transportation modes, fatigue-related accidents are greater during the night, namely during the circadian trough of alertness. Although algorithms and/or ITS have been proposed, these technologies have not yet been validated against unmasked circadian data. To our knowledge, very few studies have even attempted to adequately assess circadian phase in the field. We strongly recommend that clear validation procedures with a cost-effective approach are undertaken, to design tools that will help efficiently and rapidly assess circadian phase in multimodal transport systems.

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