Countermeasures for fatigue in transportation

A review of existing methods for drivers on road, rail, sea and in aviation

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Abstract

The overall aim with this study was to gather knowledge about countermeasures for driver fatigue (including sleepiness) in road, rail, sea and air transportation. The knowledge has been used as an input for evaluating advantages and disadvantages with different countermeasures and to estimate their potential to be used regardless mode of transportation. The method used was a literature review and a workshop with experts from all transportation modes. At the workshop the effectiveness of countermeasures for a single mode, but also regardless mode were discussed and a ranking was done.

The report discuss the potential of fighting fatigue among drivers for specific mode of transport but also from a more generic point of view, considering scheduling, model prediction of fatigue risk, legislation, a just culture, technical solutions, infrastructure, education, self-administered alertness interventions and fatigue risk management (FRM). The overall judgement was that a just culture, education, possibility to nap and schedules taking the humans limitations into consideration as the most effective countermeasures to fight fatigue, regardless mode of transportation.
Det övergripande syftet med detta arbete har varit att samla den kunskap som finns kring hur man på bästa sätt kan motverka att förartrötthet uppstår hos förare i de olika transportslagen väg, järnväg, sjö och i luften. Insamlad kunskap har använts för att bedöma för- och nackdelar med motåtgärderna och för att bedöma deras transportslagsövergripande potential. Studien omfattar en litteraturgenomgång och en workshop med experter från de olika trafikslagen vid vilken motåtgärder diskuterades och rangordnades efter upplevd effektivitet såväl enskilt som transportslagsövergripande.

Rapporten diskuterar potentialen av motåtgärder för att minska förartrötthet i olika transportslag men även transportslagsövergripande. Det som beaktas är i synnerhet schemaläggnings, modellprediktion av trötthetsrisk, lagstiftning, en rättvis kultur, tekniska lösningar, infrastruktur, utbildning, själv-administrerad trötthetsintervention, fatigue risk management (FRM). Den samlade bedömningen var att de mest effektiva transportslagsövergripande åtgärder för yrkesverksamma förare är en förlåtande kultur, det vill säga att det alltid är mer korrekt att rapportera problem som uppstått än att inte rapportera dem, utbildning, möjligheter att kunna ta en tupplur och schemaläggning som beaktar människans begränsningar.

**Referat**

Det övergripande syftet med detta arbete har varit att samla den kunskap som finns kring hur man på bästa sätt kan motverka att förartrötthet uppstår hos förare i de olika transportslagen väg, järnväg, sjö och i luften. Insamlad kunskap har använts för att bedöma för- och nackdelar med motåtgärderna och för att bedöma deras transportslagsövergripande potential. Studien omfattar en litteraturgenomgång och en workshop med experter från de olika trafikslagen vid vilken motåtgärder diskuterades och rangordnades efter upplevd effektivitet såväl enskilt som transportslagsövergripande.

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**Titel:** Motåtgärder mot förartrötthet i olika trafikslag – En granskning av existerande motåtgärder på väg, järnväg, sjö och i luften

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Foreword

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Quality review

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Kvalitetsgranskning

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Summary

Countermeasures for fatigue in transportation – A review of existing methods for drivers on road, rail, sea and in aviation

by Anna Anund (VTI), Carina Fors (VTI), Göran Kecklund, Wessel van Leeuwen and Torbjörn Åkerstedt (Stressforskningsinstitutet, Stockholms universitet)

The overall aim with this study was to gather knowledge about countermeasures for driver fatigue (including sleepiness) in road, rail, sea and air transportation. The knowledge has been used as an input for evaluating advantages and disadvantages with different countermeasures and to estimate their potential to be used regardless modes of transportation. The method used was a literature review and a workshop with experts from all transportations modes. At the workshop the effectiveness of countermeasures for a single mode, but also regardless mode were discussed and a ranking was done.

This report sets out from the observation that a considerable part of the crashes in transportation involving professional drivers (road, rail, air or sea) are due to fatigue/sleepiness and that one of the causes is that work and rest are displaced to suboptimal times due to the need for around-the-clock operations. The resulting imbalance has its effects on fatigue through 1) work during the circadian phase when body metabolism is reduced (night) 2) the extended time awake, resulting from night work hours being added to a relatively normal waking span 3) shortened daytime sleep due to circadian interference with recovery processes during the day 4) time on task effects due to demands on constant attention. There is also evidence that sleepiness crashes on road with nonprofessional drivers occur due to other factors than those work related. In terms of risk time of the day and hours slept plays an important role, but also factors as age, different type of sleep disorders and personality. The bulk of the report summarizes ways of counteracting fatigue or its consequences regardless transportation mode. However, drivers on sea, rail and in air are more or less always professional drives, in opposite to drivers on the road. This needs to be considered

Scheduling. The most important countermeasure is reasonable work scheduling that avoids night work, short daily rest, long time awake, compressed work schedules, long work shifts, and several other details of work schedules. All factors have evidence based support.

Model prediction of fatigue risk. This approach, based on mathematical expression of the factors causing fatigue, is used to identify work schedule characteristics with high fatigue risk (and improve scheduling). Despite face value, the evidence base of the application of model prediction is scant.

Legislation. Legislation should support creation of ergonomically sound and safe work schedules. Most laws and regulations include restriction of work shift duration (from 9h in road transport to 14 in sea transport). Daily rest time is covered for all modes of transportation (6h at sea and 11-12h for the other modes). Work load is considered only in air transport (shorter flight duty with more take offs). Time of day, which is the most important aspect, is not acknowledged in any legislation, except for a modification of duration during night flying. Here is an important area of improvement.

A just culture. This refers to a just and forgiving response to vehicle operators’ self-report of incidents and fatigue. Absence of a just culture will conceal risk

Technical solutions. These include alertness monitoring devices (e.g. measuring the lateral variability of the vehicle, cameras analyzing eye blink durations) that signal when a dangerous level of sleepiness has been reached. These are mainly used in road transport and lack scientific validation. Another approach is "dead man’s hand" in rail traffic (failure to respond to a attention signal causes warning sounds and eventual breaking of the train). Similar approaches have been tried at sea (but without
No validation has been carried out but the face validity is high. Also introduction of slight cognitive load may prevent sleepiness.

**Infrastructure.** Various types of road surface alterations outside the road/lane that produce noise/vibrations when a wheel of the vehicle runs over them ("rumble strips) have been used with success in road transport. Similarly, the Automatic Train Control system (ATC), which stops (after warnings) the train if the driver does not respond to the signal system. The system may take command over the train. The validity seems very high. Sea and air transport has no corresponding systems even if automatic systems for start and landing may be used (without direct links to pilot performance). None of the systems prevent fatigue, only its consequences.

**Education.** Knowledge of the signs, effects and causes of fatigue is needed in all modes of transport work. There is, however, no validation of the effects of education on fatigue or its consequences, but the face value is high. Systematic programs across transport modes should be encouraged (including validations of its effects).

**Self-administered alertness interventions.** This includes stopping the vehicle, napping, intake of caffeine, or use of bright light. All are evidence based approaches, even if some have not been tried in all modes of transportation. Road and air transport has seen much of this work. The use of interventions will depend on education.

**Fatigue risk management (FRM).** This combines fatigue education, self-report of incidents, and mathematical risk modeling. The approach puts the burden of protection from fatigue on the organization rather than on the legislator or the individual operator. Application has mainly been seen in air transport, but little validation is available. There is need for development of systematic approaches across modes of transport.

Countermeasures effectiveness **regardless transportation mode** was focused on just culture, education, possibility to nap and schedules taking the humans limitations into consideration.
Sammanfattning

Motåtgärder mot förartrötthet i olika trafikslag – En granskning av existerande motåtgärder på väg, järnväg, sjö och i luften

av Anna Anund (VTI), Carina Fors (VTI), Göran Kecklund, Wessel van Leeuwen och Torbjörn Åkerstedt (Stressforskningsinstitutet, Stockholms universitet)

Det övergripande syftet med detta arbete har varit att samla den kunskap som finns kring hur man på bästa sätt kan motverka att förartrötthet uppstår hos förare i de olika transportslagen väg, järnväg, sjö och i luften. Insamlad kunskap har använts för att bedöma för- och nackdelar med motåtgärderna och för att bedöma deras transportslagsövergripande potential. Studien omfattar en litteraturgenomgång och en workshop med experter från de olika trafikslagen vid vilken motåtgärder diskuterades och rangordnades efter upplevd effektivitet såväl enskilt som transportslagsövergripande.

Rapport utgår från observationen att en ansenlig del av transportolyckorna med yrkesutförare (vägtrafik, järnvägstrafik, sjöfart och luftfart) beror på trötthet/sömnighet och att den huvudsakliga orsaken är att arbetet och vila (sömn) är förlagda till suboptimala tider på dygnet på grund av kravet på dygnet-runt-service. Den resulterande obalansen har påverkat trötthet genom 1) att arbetet förläggs till den circadiana fas (tid i dygensrytmen) då kroppens ämnesomsättning är reducerad (dvs natten) 2) den förlängda vakentiden, som orsakas av att man adderar arbetstid till en föregående relativt lång vakentid 3) en förkortad dagtidssöm orsakad av att dygnsrytmen vid denna tid stör återhämtningsprocessen 4) time-on-task effekter som beror på kraven på konstant uppmärksamhet för den som framför fordonet. Det finns även klara bevis för att sömnighetsrelaterade olyckor på väg med ej yrkesförare ofta har en bidragande faktor av tid på dygnet och sovda timmar, men även ålder och sömnstörningar och andra personliga förutsättningar har betydelse. Huvuddelen av rapporten summerar olika sätt att motverka trötthet eller dess konsekvenser och gäller transportslagsövergripande.

Schemaläggning. Det viktigaste motmedlet är rimlig schemaläggning som undviker nattarbete, kort dygnsvila, lång vakentid, komprimerade arbetsscheman, långa arbetspass och flera andra negativa schemaspeckter. Alla dessa faktorer har stöd från vetenskapliga studier.

Modellprediktion av trötthetsrisk. Detta angreppssätt, baserat på matematisk sammanvägning av faktorer som orsakar trötthet, används för att identifiera schemaspeckter med stor trötthetsrisk (för att förbättra schemaläggningen). Trots sunt förnuft är det vetenskapliga stödet för trötthets förbättringar genom modellprediction sällsynt.


En rättvis kultur. Detta avser arbetsgivarens förståelse för och acceptans av förarens självrapportering av trötthet och relaterade incidenter. Frånvaro av förståelse kommer att dölja kunskap om trötthetsrisk i arbetsscheman.

Infrastruktur. Olika typer av ingrepp i vägytans sida som avgör ljud och vibrationer när ett däck kommer i kontakt med dem (”bullerremser”) används med framgång inom vägtransporter. Inom tågtrafik används det automatiska tågkontrollsystemet (ATC) som stoppar tåget (efter varningsljud) om inte föraren utför de åtgärder som järnvägens signalsystem kräver. ATC kan i princip ta över framförandet av tåget. Systemet har en hög effektivitet. Inga liknande system finns inom sjö- och luftfart även om automatiska system kan ta över till exempel start och landning (utan koppling till felaktigt handlande av piloter).


Fatigue risk management (FRM) (hantering av trötthetsrisk). Denna typ av motmedel kombinerar utbildning, självrapportering av trötthet/incidenter och matematisk riskmodellering. Angreppssättet lägger ansvaret om skydd från trötthet på organisationen snarare än på lagstiften eller den individuella föraren/operatören. Användning har hittills mest skett inom lufttrafik (i USA krävs modellutvärdering för att FAA skall godkänna flygruptcy), men valideringsförsöken av konceptet (mot minskad trötthetsrisk) har inte utvärderats i någon större omfattning. Här behövs utveckling av systematiska angreppssätt tvärs över olika transportslag.

Transportslagsövergripande motåtgärder med störst potential bedöms för yrkesverksamma förare vara en förlåtande kultur, det vill säga att det alltid är mer korrekt att rapportera problem som uppstått än att inte rapportera dem, utbildning, möjligheter att kunna ta en tupplur och schemaläggning som beaktar människans begränsningar.
1. Introduction

1.1. What is sleepiness and what is fatigue?
Sleepiness is common in transport operations and is regarded as a significant cause of crashes and safety-critical events. The main determinants of sleepiness are the time of day (circadian rhythm) and the duration of time awake, and prior sleep (homeostatic regulation) (Czeisler and Gooley 2007, Åkerstedt, Connor et al. 2008). In addition, work factors may also play a role for the level of sleepiness. A laboratory experiment showed that monotonous work was as harmful as moderate sleep loss (4 hours of night time sleep) for sleepiness and performance (Sallinen, Härmä et al. 2004). The operational definition for sleepiness is: “a physiological drive to fall asleep” (Dement and Carskadon 1982).

Fatigue on the other hand may also be due to exogenous and endogenous task factors such as monotonity, task demand (workload) and task duration (Di Milia, Smolensky et al. 2011) and may arise when there is an absence of a physiological drive to fall asleep. Fatigue is a related concept to sleepiness but difficult to define. It often refers to an inability or disinclination to continue an activity, generally because the activity has, in some way, been going on for “too long” (Bartley and Chute 1947).

Sleepiness and fatigue are intertwined. Not only is it difficult to isolate one from the other, it is also likely that they are differently influenced in combination with other driver states like chronic stress, mental load and chronic pain, which are among the most common public health problems. Prior sleep and sleepiness but also stress and illness are consistently connected to fatigue (Åkerstedt, Axelsson et al. 2014). How this influences performance while driving is not known. Additionally, chronic pain that leads to a dysregulation of the stress/metabolic system has been associated with disturbed sleep and increased levels of sleepiness, but how it affects driving is unknown.

Factors that have been found to contribute to fatigue and/or sleepiness are stopovers (for train drivers), which tend to result in poor sleep quality (Wilson, Marple-Horvat et al. 2008, 2011). In general irregular working hours (Wilson, Marple-Horvat et al. 2008), early morning shifts, particularly in combination with monotonous driving (Thiffault and Bergeron 2003, Barth, Barth et al. 2009, Bella and Calvi 2013), nightshifts (Stanton and Young 1998, Wilson, Marple-Horvat et al. 2008, Barth, Barth et al. 2009, Bella and Calvi 2013), long shift duration (Stanton and Young 1998, Barth, Barth et al. 2009, Bella and Calvi 2013), short sleep length (Stanton and Young 1998), high workload (Stanton and Young 1998), and monotonity and low task demand (Dunn and Williamson 2012) are contributing factors. These factors are also essential contributor in other transportations modes. Given the great impact of work hours, scheduling is probably to most essential part of fatigue risk management for the railroad industry, but other components may be relevant as well (Härm, Sallinen et al. 2002, Sallinen, Härm et al. 2003).

In the context of transportation, mental fatigue and sleepiness have the most important effects on operator performance (Williamson, Lombardi et al. 2011). Other terms like drowsiness and tiredness are considered equivalent to sleepiness. The terms sleepiness and fatigue are often used synonymously even though the causal factors contributing to the driver1 state may differ (May and Baldwin 2009). In this study we use the word fatigue as a generic term.

1.2. How to measure sleepiness and fatigue
The absolute level of fatigue is very difficult to measure and different approaches are used. Electroencephalography (EEG) is often seen or at least hoped to be the “true” marker or golden standard of sleepiness, even though there is limited knowledge regarding how sleepiness is expressed.

1 The term ”driver” also refers to pilot in aviation, navigators at sea and train drivers.
in EEG recordings of active individuals, especially when it comes to car driving (Sahayadhas, Sundaraj et al. 2012).

It is also difficult to measure EEG in real life car driving and the recordings are very sensitive to physical movements and other sources of artefacts. Other common indicators are those obtained from the blink complex, measured either through camera-based detection or through obtrusive measures such as EOG (electrooculogram) (Ingre, Åkerstedt et al. 2006, Schleicher, Galley et al. 2008). The eye movement indicators are for example blink duration, frequency, saccades, open or close velocity. There are also other physiological measures such as heart rate variability, galvanic skin response, breathing etc. that have been proposed to measure fatigue, although these have limited validity. They are very sensitive to external (non-fatigue) factors and so far not very useful for detection of driver fatigue. Another type of fatigue indicators refers to driver performance parameters such as speed, lateral position, steering wheel angel etc. These are often measured through vehicle-integrated sensors. Finally there are indicators were the drivers self-report their levels of sleepiness, for example the Karolinska sleepiness scale (Åkerstedt and Gillberg 1990). Some experts claim that self-reported sleepiness is unreliable but a recent review showed that subjective sleepiness ratings are very sensitive to time of day and sleep restriction, and correlated with physiological and behavioural indicators of sleepiness (Åkerstedt, Anund et al. 2014).

1.3. Crashes and risk factors

Severe operator fatigue occurs in all transport modes even though they operate in different context, with different level of interactions with other users and under different requirements of time pressure. Hence, unintentional nodding off at work (measured with EEG) has been demonstrated in truck drivers (Mitler, Miller et al. 1997), in train drivers (Torsvall and Åkerstedt 1987), in aviation pilots (Wright and McGown 2001), and in bridge officers at sea (Van Leeuwen, Kircher et al. 2013). All the cited studies show that severe sleepiness mainly occurs at night time and when those involved are suffering from sleep loss.

Road

Driver fatigue is a contributing factor in 15-30% of all road crashes (Horne and Reyner 1995, Connor, Norton et al. 2002). A particularly increased risk has been reported when driving during the night or early morning hours (Horne and Reyner 1995, Åkerstedt and Kecklund 2001, Stutts, Wilkins et al. 2003, 2004), for young (Lowden, Anund et al. 2009, Filtness, Reyner et al. 2012) and for professional (Hanowski, Wierwille et al. 2003, Klauer, Dingus et al. 2006, Hanowski, Hickman et al. 2007) drivers, shift workers driving home after a night shift (Åkerstedt, Peters et al. 2005, Ftowni, Sletten et al. 2013), and for people with untreated sleep disorders (Hanowski, Wierwille et al. 2003, Klauer, Dingus et al. 2006, Hanowski, Hickman et al. 2007, Philip, Taillard et al. 2009). Driving when sleepy impairs driving performance causing deteriorated lateral and longitudinal control of the vehicle. With increased levels of sleepiness, these deteriorations become more and more severe and will eventually lead to lane departures (Åkerstedt, Hallvig et al. 2013). However, many studies report large differences between individuals even in the case of known risk groups (Ingre, Akerstedt et al. 2006, Van Dongen 2007).

Rail, sea and aviation

There are several anecdotal reports, for example in-depth investigations, of accidents in rail, sea and aviation showing that driver fatigue contributed to the incident (NTSB 1999). Compared to road transportation, systematic crash investigations are lacking for railroad, sea and aviation – with a few exceptions. US National Transportation Safety Board (NTSB) reported that the prevalence of fatigue-related accidents in aviation was 21%, which was based on statistics from Federal Aviation Administration (NTSB 1999). However, if only reports that specifically mention fatigue are included,
the prevalence drops to 4% (NTSB 1999). NTSB estimated the prevalence of fatigue-related marine accidents to 16% (or 33% of the accidents that included personal injuries). NTSB could not reliably estimate the prevalence of fatigue-related accidents for railroad transportation since most investigation reports did not address the train driver’s wakefulness level prior to the accident.

1.4. Countermeasures

In order to reduce crashes with people being killed due to operator fatigue, countermeasures are needed. From a theoretical point of view, the most promising countermeasures will be those that contribute to the decision not to drive at all when there is a risk of being fatigued (Haddon 1972). During the drive, there are critical decisions a driver needs to take in order to avoid the risk of a sleep-related crash. First of all, the driver has to recognize the sensation of sleepiness. In the next step, the driver must be motivated to take corrective actions, and have knowledge of which countermeasures are effective and whether the alertness increasing effect is long-term. Finally, the driving circumstances should allow the driver to act according to an effective strategy, as shown in Figure 1. The drivers’ preference for countermeasure will not only influence the motivation to fight fatigue, but also the probability of choosing an effective countermeasure will be influenced.

![Figure 1. The chain of decisions in order to avoid increased risk of crash when the driver is fatigued.](image)

From a generic perspective, there is relatively strong support from laboratory studies that self-administered countermeasures such as napping, bright light exposure, caffeine, melatonin administration, and use of hypnotics (sleep medication) reduces fatigue or increases sleep length (Pallesen, Bjorvatn et al. 2010). These countermeasures are often recommended in fatigue management education programs.

Countermeasures might also be addressed on a more organizational level like Fatigue Risk Management (FRM), education/information programs etc. (Michon 1985). FRM has started to gain attention as a more effective way to handle fatigue-related risks in complex organizations, and one of the used definition of FRM is: “...the planning and control over the working environment, in order to minimize, as far as is reasonable practicable, the adverse effects of fatigue on workforce alertness..."
and performance, in a manner appropriate to the level of risk exposure and the nature of the operation” (Gander, Hartley et al. 2011). In addition they define a FRM systems as “A scientifically based and flexible alternative to rigid work time limitations, that provides a layered system of defenses to minimize, as far as is reasonably practicable, the adverse effects of fatigue on workforce alertness and performance, and the safety risk that this represents”.

There are several approaches of FRM and in a review a total of 61 different programs were identified. The review included all types of transport modes with 16 FRM for aviation, 6 for rail, 7 for sea and 32 for road transportation (Philips and Sagberg 2010). They all consist of different concepts and control mechanisms. One of the more extended ones identifies five levels of identifiable hazards and controls where the levels are concerned with drivers; Sleep opportunity, actual sleep, behavioral symptoms, fatigue related errors and fatigue related accidents (Dawson and McCulloch 2005). The authors also describe a wide range of possible control mechanisms such as hours-of-service (HoS) rules, prior sleep-wake-modelling, prior sleep-wake-data, symptom checklists, self-report behavioral scales, fatigue proofing strategies, a safety management system error analysis system and a safety management system incident analysis system are all required in order to handle the complexity of fatigue risk management. One common observation however is the lack of systematic evaluations whether the introduction of FRM reduces fatigue and improves safety.
2. Aim

The overall aim with this study is to gather knowledge about countermeasures for driver fatigue (including sleepiness) in road, rail, aviation and sea transportation.

The study will also be evaluate advantages and disadvantages with different countermeasures and estimate their potential to be used in all modes of transportation.

The research questions identified are:

- What are the laws, regulations and constitutions that primary and secondary influence driver fatigue?
- What is the menu of countermeasures for driver fatigue?
- What countermeasures are proven to be effective or not effective?
- What countermeasures are expected to be useful for all types of driver fatigue, regardless transportation mode?
3. Method

The project consists of five different steps;

1. A literature review took place where scientific studies about countermeasures were included, but also a review of existing rules, regulations and standards related to driver fatigue or sleepiness. The main sources used were Summon, Scopus, Goggle Scholar and PubMed and literature from 2004-2014 were included. We also decided to not include details for example algorithms for detection, rather studies on a more generic level.

2. In the second step a workshop was held with a total of 23 experts from different transport modes. The experts were presented the results from the literature review and those were discussed and ratings of the most promising once per transport mode and from a generic perspective took place.

3. Based on what we learned from step 1 & 2 a draft report was written

4. An expert panel was invited and the draft version of the report was send to them to be reviewed.

5. Finally their comments were regarded and the report was finalized.
4. Result – Road

4.1. Laws and regulations


This is the general Swedish law for working hours for all professions. Some parts of this law can be overruled by collective agreements.

*The Road Traffic and Traffic offenses Law* (Trafikförordningen and Trafikbrottslagen)*

From a generic point of view it is against the Swedish law to drive in a sleepy condition (“uttröttning”). This is regulated in the Trafikförordningen 1998:1276, Chapter 3 §1. This is the same law that says it is against the law to drive under influence of alcohol. However, for sleepiness the law is not linked to a punishment directly as it is for alcohol with a clear limit of 2‰ blood alcohol (BAC) concentration. Instead the punishment is connected to the Trafikbrottslagen (TBL 1951:649 1§) and seen as reckless driving.

*Transport Agency’s Statute Book* (Transportstyrelsens författningssamling)

There is also a generic constitution (TSFS 2012:19) that regulates the right to a driving license in relation to different types of medical impairments. In Chapter 11 §1 it is clearly expressed that in order to have the right to a driving license of type AM, A1, A, B, BE, C, CE, D, DE, tractor or taxi license the person should not suffer from sleep apnea, snoring disorder (“ronkopati”) and other disease with sleep disorder or narcolepsy in such a way that it involve a road safety risk. For professional drivers it is even more clear and §2 says that for a license of C, CE, D, DE or taxi the increased risk of reduced safety with such a driving license should be regarded.

The constitution also points at the need for a medical certificate for patients with disease were the risk of falling asleep while driving is high. Some of the mentioned diseases are diabetes, Parkinson’s and epilepsy. However, it is unclear how to judge if a person is affected by the disease in a way that will increase the risk of sleepiness while driving.

For persons in the age of 45 or older and with drivers licence C1, C1E, C, CE, D1, D1E, D and DE there is a requirement of medical certificate once each 5 year*4* The control is rather simple and there might be reason to use this opportunity to addresses occupational health issues related to both primary and secondary sleep related issues like sleep patterns, obesity, smoking, alcohol intake etc.

*Driving and rest times* (2008:475) (Kör och vilotider)

The purpose of the regulations concerning driving and rest periods is primarily in connection with the transport policy principle of fair competition and good working conditions, but it is also a link to the transport policy (“hånsyns målet”) that aims to reduce the number of fatalities and serious injuries in road traffic.

The regulation mainly regulates the minimum length of breaks, daily and weekly rest periods, and maximum driving time. Indirectly, these rules determine how a work schedule can be designed. What to do during breaks and rest periods is not regulated as long as there are not work-related tasks. It should be pointed out that the hours of service regulations is mainly a competition law and not a law to avoid fatigued drivers.

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*2 Swedish laws are available at [http://www.riksdagen.se/sv/Dokument-Lagar/Lagar/](http://www.riksdagen.se/sv/Dokument-Lagar/Lagar/)
*3 The Swedish Transport Agency’s Statute book is available at [http://www.transportstyrelsen.se](http://www.transportstyrelsen.se)
Regulatory framework stipulates a minimum 45-minute break after a driving period of 4.5 hours. Breaks may be divided into two, but the last break needs to be 30 minutes long. Some evidence for biological conditions in terms of, for example, driving for 4.5 hours before the rest during day time is not known to the best of our knowledge. In fact 4.5 hours of continuous driving have been proven to be too long for a driver to stay alert during night time (Philip, Sagaspe et al. 2005).

**Driving time:** Maximum 9 hours driving per day (2 times a week you may drive 10 hours). In total you may drive 56 hours per week.

**Daily rest:** During a 24 hours period (30 hours if you are more than one driver) you need to rest at least 11 hours (normal rest) or 9 hours (reduced rest). A driver is permitted to have maximum 3 periods of reduced rest within two “week rest” periods.

**Week rest:** At least 45 hours (possible to reduce to 24 hours with a compensation within four weeks).

### 4.2. Self-administrated countermeasures

The most common self-administered countermeasures involve stopping for a short walk, turning on the radio/music player, opening a window (Stutts, Wilkins et al. 1999, Anund, Kecklund et al. 2008). It has also been shown that there are differences between groups of drivers regarding the willingness to do the most promising one, that is, to stop for a nap (Anund, Kecklund et al. 2008). Drivers with experience of sleep related crashes or of driving during severe sleepiness, as well as professional drivers, males and drivers aged 46-64 years were those practicing “stop for a nap” as a countermeasure for sleepiness.

Most studies are done in driving simulators and very few countermeasures are systematically evaluated on real roads. From simulator studies there is evidence that taking a nap or/and caffeine is effective (Horne and Reyner 1996), but also drinking functional energy drinks (Reyner and Horne 2002). In contrast, using cold air or turning on the radio does not show significant effects (Reyner and Horne 1998). This is also supported by the results from a real road driving study (Schwarz, Ingre et al. 2012). We also know that using a rest stop will help in reducing fatigue related crashes (Reyner, Flately et al. 2006).

### 4.3. Technical solutions

Already 20 years ago (Lisper, Laurell et al. 1986) concluded, “what is the use of alerting a driver already aware of the fact that s/he is close to sleep but who unwittingly still continues to drive?”. The fact that the drivers are aware of their sleepiness signs is also supported by other studies (Kaplan, Itoi et al. 2007, Nordbakke and Sagberg 2007, Anund and Åkerstedt 2010). One conclusion that might be drawn is that the drivers are aware of the signs but do not have the possibility to foresee the sleep onset.

There are discussions of how to use technical solutions from a more strategic point of view in order to reduce the development of sleepiness. One of those concepts is bright light, that suppresses melatonin, and which peaks in the late night hours (Lowden, Akerstedt et al. 2004, Bjorvatn, Stangenes et al. 2007). Blue light has been proven to be effective, but difficult to administer in the car without impairing other aspects of vision (Taillard, Capelli et al. 2012). It has been demonstrated that, on a strategic level, a combination of nap and bright light exposure before driving may reduce sleepiness (Leger, Philip et al. 2008).

Despite the fact that most drivers are aware of their level of sleepiness there has been considerable development in the area of driver support systems, focused on feedback/warning on hazardous driving (Brookhuis and de Waard 1993, Dinges and Mallis 1998) or on the physiological state of the individual sleepiness (Wierwille and Ellsworth 1994, Åkerstedt and Folkard 1997, Horne and Reyner 1999). The effectiveness of these systems is extremely difficult to evaluate since simulators probably
are not realistic enough. How those evaluations are done is of major concern since there is a risk of a confusion between what is sleepiness related and what is task related fatigue (May and Baldwin 2009). There is also a risk that the context that is used to investigate this is rather irrelevant to the drivers (Baulk, Reyner et al. 2001, Horne 2013). There is a need for studies on real roads. In addition it is important to keep in mind that the influence of the drivers is not only an effect of the correctness in the detection or the prediction. It is also an effect of the warning strategy, which could be a system based on feedback to the driver, warning and intervention during different phases of sleepiness.

Driver sleepiness detection and prediction systems can be categorized into four groups (Dinges and Mallis 1998).

1. Readiness-to-perform and fitness-for-duty technologies
2. Mathematical models of alertness dynamics joined with ambulatory technologies
3. Vehicle-based performance technologies
4. In-vehicle, on-line, driver monitoring technologies

The four categories do in some way describe a time line with the “fit for duty test” as a strategic measure to beforehand indentify those not fit to drive. The beforehand predictions is still not fully trustable, even though there are papers that indicate that it might be possible to predict those terminating a driver due to server sleepiness (Åkerstedt, Hallvig et al. 2013), most research show that it is challenging to find a stable indicator (Ahlström, Nyström et al. 2013), but also to find sensors that do not suffer from countounding from the context or other driver states such as stress, cognitive load etc.

In a review from 2009 the state of the art of drowsiness detection systems was presented (Wilschut, Caljouw et al. 2009). The identified systems were divided into groups of systems depending on the hardware and software integrated. One group was systems based on eye detection (CoPilot, Optalert, Driver Fatigue Monitor – PERCLOS, Driver State Monitor – AVECLOSE, Attention Assist – Daimler AG, FaceLab, Seeing Machines, CRAM, ETS-PC Eye Tracking system, Anti-Sleep – SmartEye etc.). Most of these systems use IR cameras and measures eye closures, gaze and pupil size. The systems still have difficulties to handle eyeglasses, low sun, looking down for too long. This means that you will have lack of performance with false alarms as a consequence. In relation to future automated driving, one aspect highlighted is the need for robust and cost effective sensors in this area (Horizon 2020).

A second group of systems are those based on physical activity like for example MINDStim. However those type of systems is still rather immature systems with unproven impact.

A third group are those that is developed by the car industry. Most manufacture have some sort of systems on the market or coming for example Nissan, Toyota, Volvo Car Cooperation, Daimler, BMW, Ford, etc). They normally use vehicle integrated sensors looking mainly at drivers’ lateral performance (steering and keeping a stable position in the lane).

Finally there is a group of systems that use a multiple measure approach. These systems combine different types of sensors some example that are on the market are ASTID, DDS, SAFETRAC.

In a review of technical soloutions from 2014 it was concluded that none of avaialble detectio systems were sufficiently well validated to provide a comprehensive solution to managing fatigue-related risk at the individual level in real time. Nevertheless, several of the technologies may be considered a potentially useful element of a broader fatigue risk management system. (Dawson, Searle et al. 2014). The in-vehicle, on-line category refers to a broad array of approaches and techniques that seek to monitor bio-behavioral characteristics of the driver, e.g. eye movements, head movements, electrical brain activity (EEG) etc., continuously during driving. The emphasis is on technologies that are relatively unobtrusive and are practical to use in the vehicle. Earlier literature reviews have mainly
focused on presenting existing systems, guidelines and European standards, without presenting the underlying theoretical foundation and evaluation of systems. Regarding literature concerning guidelines and European standards the most updated summarization, as far as we know, is the one done within the SENSATION project (Hagenmeyer L, Löher L et al. 2006).

4.4. Infrastructure

The fundamental type of sleepiness may in some cases be masked by surrounding factors, such as social interaction, stress, physical activity, coffee etc., and result in manifest sleepiness. By its nature the short-term variation in sleepiness may often be determined by environmental factors, which can both increase and decrease the sleepiness level. Thus, sleepiness is to a large extent context dependent. Despite this there are still few studies available that focus on the relation between the context and the development of sleepiness, either on the relation between crashes and driver sleepiness. An exception is monotony and a monotonous road contributes to fatigue symptoms (Dinges and Kribbs 1991, Thiffault and Bergeron 2003).

A related interesting question is the relation between the road design (lane width, curvature, visibility of lane markings etc.) and driver sleepiness. There may be countermeasures from a road construction perspective that could be used in order to reduce the development of sleepiness while driving. Further studies are needed. In studies comparing laboratory with simulators it has been proven that the increase of sleepiness is faster in monotonous driving scenarios (Richter, Marsalek et al. 2005). In a simulator study there were no difference in the development of sleepiness when the participants were driving without interaction with other drivers compared (free driving) to if they were following other cars (Anund, Kecklund et al. 2009). The authors concluded that the same levels of sleepiness that is normally seen in sleep related simulator studies were not present in this. This may be due to the variation between driving with no vehicles in front and driving in a car following situation. In the same study overtaking under sleepiness was looked at, the results showed that the sleepiness signs disappeared during overtaking. However, if this was a result of decreased sleepiness or if the stress and task masked the sleepiness remain unknown.

A matched case-control study showed a crash reduction among those using highway rest stops, drinking coffee or playing radio while driving (Cummings, Koepsell et al. 2001). On the other hand, a study by (Reyner, Flately et al. 2006) did not show any effect of Motor way Service Areas (MSA) or the presence or absence of “Tiredness Kills – Take a Break” signs prior to an MSA for road traffic crashes in general. However, a reduction was seen for sleep related crashes. It has also been indicated that cognitive alertness maintaining tasks prevent drowsiness (excluding sleepiness due to sleep deprivation) to some extent (Oron-Gilad, Ronen et al. 2008, Gershon, Ronen et al. 2009).

A very effective countermeasure through infrastructure is the rumble strip. Placed at the centre line it has been found to reduce crashes by approximately 15%, and the effect of rumble strips at the road shoulder is even more positive with a reduction of 40 – 50% (Mahoney, Porter et al. 2003, Persaud, Retting et al. 2003). The most recent evaluations of the effectiveness of rumble strips on Swedish roads show a reduction of severe injuries and fatalities with 30% on motorways with rumble strips at the shoulder, and a 14% reduction on 2-lane rural roads with rumble strips in centre of the road (Vadeby, Anund et al. 2013). Based on physiological indicators as well as on driving behaviour, it has been shown that sleepy drivers are alerted as they hit the rumble strip (Anund, Kecklund et al. 2008). However, the alerting effect is short-term, and after 3 – 4 minutes the driver is back to pre-hit sleepiness levels.

4.5. Education and training

In a consensus document from 2000, a panel of internationally leading sleepiness researchers agreed that driver education and information are the most effective way to fight driver sleepiness (Åkerstedt 2000). This statement was done even though evaluations of single driver education initiatives with
respect to fatigue is very rare. In Sweden, education about driver sleepiness together with discussions about drugs, alcohol and seatbelt usage are raised as an issue during the so-called “Risk 1”. Risk 1 is a mandatory part of the driving licence education. Evaluations using questionnaires show that the education might have some effectiveness of the understanding of the danger of driving under sleepiness, but at the same time there was an increase in intention for negative behaviour, related to driver sleepiness (Forward, Wallen-Warner et al. 2010). Further studies on real behaviour are needed.

4.6. Fatigue risk management

With respect to countermeasures on the strategic level, one should avoid night driving and make sure sufficient amounts of sleep have been obtained before driving. Here, the Fatigue Management Programs and work scheduling for professional drivers play a major role. In a review of theories it was argued that the most promising solutions would be to shift from a focus on Hours of Service regulations to a Safety Management System (SMS) in which fatigue is one component (Dawson and McCulloch 2005). The review of FRM summarize that there is a need for highly quality evaluations of FRM in order to learn where it has been successful and/or inform its further development (Philips and Sagberg 2010).

4.7. Concluding remarks

Problems related to sleepy driving needs to be dealt with from a holistic approach. The driver needs to know how to be prepared to avoid dangerous driving due to fatigue, but also have an understanding of the lack of insight to foresee sleep onset (Anund and Åkerstedt 2010). Here education and information might play a role even though no studies so far have been able to support the effectiveness of education and information. Drivers also need support to make the decision to stop along the road to take a nap or and caffeine, the only proven lasting countermeasures. In addition there is a need for safe and secure rest areas. The possibility to act may vary between drivers depending on if it is a private driver or a professional truck or bus driver. From the professional drivers point of view it is important that the company has a fatigue risk management policy that clearly state what to do in this kind of situation.
5. Result – Rail

Operating a train is characterized by large variations in cognitive workload, often with long periods of low activity. In addition, train drivers often have an irregular work schedule and, particularly in freight operations, a high proportion of night shifts. As a consequence, operator fatigue and sleepiness and its impact on safety critical performance is a major issue in the railroad industry (Gane 2006).

The field of rail human factors research has historically been smaller than those of aviation and road transport, although it has been growing during the 2000s (Milner, Dick et al. 1984), why there is relatively little literature on train driver fatigue and countermeasures.

5.1. Laws and regulations

There are two Swedish laws that apply to train-drivers:

- **Working hours regulation** (1982:673): This is the general Swedish law for working hours for all professions. Some parts of this law can be overruled by collective agreements.
- **Rules on driving time and rest periods in cross-border railway services (Swedish: Lag om kör och vilotid vid internationell järnvägstrafik)** (2008:475): This law applies only to train-drivers on cross-border trains and it is based on the EU directive 2005/47/EC. In short, the rules establish that the daily driving period shall not exceed 9 hours (8 hours on night shifts), there should be a break of at least 30 min if the working time is 6–8 hours (45 min if working time > 8h), and that the daily rest shall be at least 12 consecutive hours if taken at the normal residence of the driver and at least 8 consecutive hours if taken away from home.

Driving times and rest periods for Swedish train-drivers are mainly regulated by collective agreements. Each company has its own agreement and there are in total 62 different collective agreements for train drivers in Sweden. In general, there are four main types of agreements, which applies to underground/tram, commuter trains, long-distance trains and goods trains, respectively. Collective agreements for long-distance and goods trains usually allow longer shifts than those for underground and commuter trains.

Medical requirements state that a train-driver must not suffer from any medical conditions that may lead to reduced attention, wakefulness, judgment or concentration (TSFS 2013:50 and TSFS 2013:52).

5.2. Technical solutions

Many trains are equipped with some vigilance device based on the “dead man’s switch” principle. An old and relatively simple type of such a system consists of a lever that the train driver have to hold down at all times to keep the train running. Newer devices monitors various control actions, such as changes in pedal positions, and issues a warning if there haven’t been any activity from the train driver for a certain period of time (Dunn and Williamson 2012). If there is no response to the warning, the brakes are automatically applied. Even more sophisticated systems may alert the train traffic management if the driver is inactive (Ting, Hwang et al. 2008).

In a paper by Dunn and Williamson (2012), the effects of cognitive demand on monotony-related deterioration of train drivers’ performance was investigated. It was found that even a relatively small increase in cognitive demand may mitigate monotony-related effects on performance, and the authors suggest that the use of an interactive cognitive task may be effective in maintaining alertness. Examples of such tasks are trivia tasks and calculation tasks.

There are a few attempts to develop fatigue monitoring systems for train drivers reported in the literature. Technologies investigated include electroencephalography (Félez, Maroto et al. 2007, Filtness and Reyner 2010, Hallvig, Anund et al. 2014), electrodermal activity (Félez, Maroto et al. 2007, Zhang, Gu et al. 2011), electrocardiography (Félez, Maroto et al. 2007), and eye/eyelid analysis.
(Hartleip and Roggenkamp 2005, Bella, Calvi et al. 2014). To our knowledge, there are however no such monitoring systems commercially available.

5.3. Infrastructure

Automatic Train Control (ATC) or Automatic Train Protection (ATP) refer to safety systems that aim to reduce the risk of accidents caused by human errors. The Swedish ATC system prevent train drivers from exceeding the speed limit and ignoring/missing stop signals. The ATC system will eventually be replaced by the European Rail Traffic Management System (ERTMS). It is not fully clear that ATC contribute to less fatigue and it has been proven to be a risk that ATC even cause fatigue related problems (Philips 2014), however it clearly eliminates the negative consequences of fatigue for safety.

5.4. Education and training

In several countries, rail authorities and/or various organizations provide web-based material on how to reduce and counteract train driver fatigue. Most information provided by authorities and other public organizations is mainly directed towards train operators and usually include some basic facts about fatigue and related risk factors, assessment of risk factors and strategies to address those and guidelines for fatigue risk management (Kotterba, Mueller et al. 2004, Desai, Wilsmore et al. 2007, Garay-Vega, Fisher et al. 2007, Merat and Jamson 2013). Similar information is provided by some industrial organizations and train drivers’ unions (Hernandez, Newcomb et al. 1997, Green and Reed 1999, Brémond, Bodard et al. 2013, Edensor 2013).

In the US, the Federal Railroad Administration and Harvard Medical School have published a website directed towards railroad workers (Hogema and Horst 1994). This website provides a comprehensive guide on how to improve sleep and avoid sleep related problems, including some tools and tests. Training and education are also offered by some commercial companies, e.g. (Plainis and Murray 2002, Fatigue Management Solutions 2014).

We haven’t been able to find any scientific publications on the effectiveness of education and training on train driver fatigue.

5.5. Fatigue risk management

Some tools to manage operator fatigue, directed towards all modes of transport, have been developed by the U.S. Department of Transportation, within a program called Operator Fatigue Management Program (Gane 2006, Savijärvi 2014). The program includes four parts: 1) A work schedule representation and analysis software, which helps managers to evaluate work schedules in order to promote alertness 2) A business case development tool, which consists of case studies on the economic effects of operator fatigue and fatigue management programs, 3) A fatigue model validation procedure, which is a set of procedures for validating the output of fatigue modelling tools, and 4) A fatigue management reference guide, which is a compendium of current science and practical information on approaches to fatigue management and mitigation in the transportation enterprise.

A tool for analysing and comparing different shift schedules, called the Fatigue and Risk Index (FRI) is provided by the Health and Safety Executive in the UK (HSE 2014). This tool calculates one fatigue index and one risk index, based on cumulative fatigue, time of day, shift length, breaks and recovery from a sequence of shifts.

A regulatory framework for rail safety with respect to fatigue is currently being discussed by the National Transport Commission in Australia. In a paper by Anderson et al (2012), some recommendations for this framework is given. They suggest that the framework should:

- Prescribe hours of work and rest
• Include a comprehensive sleep disorder management program
• Utilise validated biomathematical tools as a part of the organisational-level fatigue risk management system

In a Swedish project called TRAIN, which aimed at investigating train driver work situation, the following recommendations on fatigue countermeasures were given (Kecklund and The TRAIN project group 2001, Wilson, Marple-Horvat et al. 2008):

• Introduce at least 12 h rest between shifts to avoid serious lack of sleep and critical fatigue.
• Sleep loss and fatigue should be compensated with rest and recuperation and not with economical compensation.
• Avoid compressed work hours (many workdays in succession).
• Work more toward forward rotation of schedules.
• Rehabilitate risk groups (drivers with e.g. chronic insomnia or chronic persistent fatigue).
• Use fatigue modelling tools to improve work scheduling.

Although there are many recommendations for shift scheduling in the literature and provided by authorities and organizations, there is a lack of controlled intervention studies on shift systems (Barth, Barth et al. 2009). The scientific basis of the present schedule recommendations may thus be somewhat weak.

There are some validation studies of biomathematical models of alertness and fatigue published. Darwent et al (2013) have evaluated the predictive validity of a novel version of a previously published sleep predictor model, by comparing the predicted sleep periods with data collected from a sample of train drivers, and found a good agreement. Hursh et al (2012) have suggested and investigated a method for validation and calibration of a biomathematical fatigue model. The study showed that a biomathematical fatigue model can relate work schedule to an elevated risk of railroad accidents and it was concluded that this provides a strong scientific basis for evaluating work schedules with validated fatigue models. A possible limitation with biomathematical models is that they do not include all sources of fatigue. It has been suggested that the inclusion of workload parameters may improve fatigue prediction approaches (Stanton and Young 1998).

5.6. Concluding remarks

There is relatively little literature on train driver fatigue and countermeasures. One reason might be that there are technical solutions in the railroad industry, such as systems based on the “dead man’s switch” principle and the ATC/ATP systems, that probably rather effectively mitigate or counteract the consequences of driver fatigue from a safety perspective. These systems are however not intended to counteract sleepiness per se and since sleepiness and fatigue has been pointed out as an issue in the railroad industry, other kinds of countermeasures are needed. Research has shown that the working hours play an important role. Scheduling and fatigue risk management is thus probably an essential part in order to reduce fatigue in train drivers, but there is however a lack of controlled intervention studies on shift systems.
6. Result – Sea

The ship as a working place is exceptional and by no means comparable to the working places in other modes of transportation, as was already put forward in the 1950s (Aubert & Arner, 1958):

- The ship is a total institution where the seafarer lives at his place of work, among his colleagues and superiors;
- The seafarer is physically isolated from the family for considerable amounts of time.

Such unique circumstances will undoubtedly influence fatigue and its possibilities of mitigating it as it does increase the psychological stress in seafarers (Carotenuto, Molino, Fasanaro, & Amenta, 2012). On the one hand, seafarers do not have domestic duties in the same way as those who live at home. On the other hand, worry over family matters at home might also be a cause of stress for seafarers.

6.1. Laws and regulations

6.1.1. European council directive 1999/63/EC

Directive 1999/63/EC (http://europa.eu/legislation_summaries/transport/waterborne_transport/c10819_en.htm) implements the International Labour Organization's (ILO) Convention on the hours of work of seafarers. This Convention was consolidated by the ILO’s Maritime Labour Convention (MLC), adopted in 2006. This Directive applies to seafarers on board every sea vessel registered in the territory of a Member State, whether publicly or privately owned, which is ordinarily engaged in commercial maritime operations. A ship that is on the register of two Member States is deemed to be registered in the State whose flag it flies. The hours of work and rest of seafarers are laid down as follows:

- either the maximum hours of work which must not exceed:
  - 14 hours in any 24h period
  - 72 hours in any 7-day period
- or the minimum hours of rest which must not be less than:
  - 10 hours in any 24h period
  - 77 hours in any 7-day period.

Hours of rest may not be divided into more than two periods, one of which must be at least six hours in length. The interval between consecutive periods of rest must not exceed 14 hours.

More or less the same regulations were taken over in the maritime labour convention that applies to all countries that have ratified it (currently 66, see http://en.wikipedia.org/wiki/Maritime_Labour_Convention). The national regulations don’t change anything regarding the working times, but only regulate the salaries, leaves etc.

The ultimate responsibility lies with the company. The master of a ship must take all measures necessary to ensure that the conditions relating to hours of work and rest are met. The master shall keep a record of the daily hours of work and rest of seafarers. Furthermore, the national authorities may request the ship-owner to provide information on the watch keepers and night workers.

In addition, regarding age, it is stated that seafarers under the age of 18 are not permitted to work at night and that no person under 16 years of age is allowed to work on a ship. Night is defined as a period of nine consecutive hours at least, commencing at the latest at midnight and ending at the earliest at 5 a.m.

In addition general fatigue management does fall within the ISM (International Safety Management) Code (which is another IMO Convention), which ensures that companies have systems in place to
manage the safety of their vessels. Also, under the various Conventions, is the principle of Port State Control, which allows inspectors to detain vessels if deficiencies are found, in this context, in the record keeping of hours of work – this is becoming more common as fatigue issues become better understood.

6.1.2. The maritime labour convention (MLC)

The maritime labour convention (http://www.ilo.org/dyn/normlex/en/?p=1000:91:0::NO) entered into force on 20 August 2013. The convention applies to all ships, irrespective of size, except fishing boats, handmade boats and war ships. The MLC defines a ship as “a ship other than one which navigates exclusively in inland waters or waters within, or closely adjacent to, sheltered waters or areas where port regulations apply”. In the case of Sweden this means that ships that travel within Sweden and outside the coast (but within one nautical mile from a port), as well as traffic in Kalmarsund and Öresund is not included. As a consequence the majority of archipelago traffic is excluded from the MLC. For this, the national regulations as discussed below, apply.

As of August 2014, the MLC has been ratified by 64 states (including Sweden) representing 80 per cent of global shipping. Regulation 2.3; standard A2.3 entitled hours of work and hours of rest states regulations that are identical to the directive 1999/63/EC mentioned above.

Slightly stricter guidelines are formulated for young seafarers under the age of 18, but these have just the status of a guideline rather than a regulation.

In addition to MLC there is also the IMO STCW Convention (Standards of Training, Certification and Watchkeeping of Seafarers), which is the international convention covering watch keeper duties and the hours of work for watch keepers, rather than all seafarers as in MLC. The STCW convention is very similar as the MLC requirements.

6.1.3. National regulations

The Swedish Maritime Administration, Sjöfartsverket, (SJÖFS 2005:24) has defined working time regulations for those working on naval ships and are aged 18 or below: (1) working hours should not exceed 8 hours per day and 40 hours per week, (2) either the time between 22:00 and 06:00 or the time between 23:00 and 07:00 should be time off, (3) at least 12 hours of interrupted time off should be present every day, (4) every seven days, a resting period of at least 36 hours should be present.

In most other cases, agreements with the labour union SEKO apply. Three such different agreements apply, called färjeavtalet (the ferry agreement), storsjöavtalet (the big sea agreement) and skärgårdsavtalet (the archipelago agreement).

Storsjöavtalet (an agreement of working conditions and salary compensation for Swedish seafarers) concerns those who are employed by shipping companies that are a member of Sjöfartens arbetsgivareförbund (SARF). Currently, 90 companies with in total 10 300 employees are members of SARF. The ordinary working times are separately defined for day workers, watch keepers, and stewards (intendenturpersonal). For day workers, the normal working times during a working week (i.e., Monday to Friday) include eight hours of work to be carried out between 06:00 and 18:00; on Saturdays it includes five hours of work to be carried out between 06:00 and 13:00. For watch keepers, the basic rule is eight hours of work per 24-hour period during all days of the week – taking care of maximizing the amount of uninterrupted time off.

Ferry Agreement (Färjeavtalet) concerns, in principle, those working on ships that hold the passenger ship certificate and working for companies that are a member of SARF. Normal working times are 37 hours per week (or a multiple of that). Scheduled working time is not to exceed 13 hours per 24h period. No differentiations are made for weekend days versus weekdays. Different regulations apply for ships that are not in service. The normal weekly working time is not to exceed 37 hours per week and the working hours should in principle take place on weekdays (i.e., Monday to Friday) between
07:00 and 17:00. Working hours outside those limits are compensated by extra holiday leave. A special agreement applies to those working on-board HSC-ships. Here the weekly working time is in principle 36 hours per week (or a multiple of that). The normal working time is not to exceed 40 hours per week and should take place on weekdays (Monday to Friday) between 07:00 and 17:00. The yearly working time agreement states that normal working time is 1749 hours per calendar year with an average of 37 hours per week. The number of working days is 165 days per calendar year. The total rest time per day and 7-day period is not to be less than what is described in the Lag om vitotid för sjömän (the law on resting time for seafarers).

The Act (1998: 958) about rest hours for mariners (Lag (1998:958) om vitotid för sjömän) can be found at http://www.notisum.se/rnp/sls/lag/19980958.htm. It is applicable to seafarers on all type of ships, except fishing boats, rescue boats, and leisure boats. Collective agreements may, however, overrule this law under the condition that it is in agreement with 3 kap. 10 § of the Maritime Safety Act (fartygssäkerhetslagen) (2003:364). The resting periods are not to be less than (1) 10 hours per every 24h period and (2) 77 hours per every 7-day period. The daily resting period may be split up in maximum 2 periods of which one should be at least 6 hours. The time between two resting periods may not exceed 14 hours. Seafarers under the age of 18 have the right to at least 9 hours of uninterrupted night rest, which should include the hours between 24:00 and 5:00. For seafarers onboard foreign ships attending a Swedish port is referred to the EU directive 1999/63/EC (see above).

Archipelago Agreement (Skärgårdsavtalet) concerns those employed by companies connected to Almega. It mainly concerns passenger/goods traffic in inland traffic. Regarding the resting times, it refers to the act about rest hours for mariners (lag om vitotid för sjömän). The normal working hours for those working full time are 5,0 hours multiplied by the number of days per month, which results on average in 35 hours per week. Due to the nature of work, no distinction is made between weekdays and weekends.

6.2. Technical solutions

The Bridge Navigational Watch Alarm System (BNWAS) was proposed to IMO’s maritime safety committee in 2005 by Denmark and the Bahamas to be added to the carriage requirements for ship borne navigational systems and equipment. After a transition period, all ships are now mandatory equipped with BNWAS as of July 2014. The functioning of such a BNWAS is also described in the IMO resolution (MSC.128(75)). In short, the system has a dormant stage together with 3 alarm stages. Upon activation of the autopilot, the BNWAS is automatically engaged:

Stage 1: Upon engagement, the bridge officer is required to signal his presence to the BNWAS every 3 to 12 minutes in response to a flashing light, either by moving an arm in front of a motion sensor, pressing a confirmation button, or directly applying pressure to the BNWAS centre.

Stage 2: When a confirmation signal does not occur within 15 seconds, an alarm will sound on the bridge; if there is still no confirmation signal after an additional 15 seconds, an alarm will sound in the captain's and the first officer's cabins. One of them must then go to the bridge and cancel the alarm.

Stage 3: If neither the captain nor the first officer cancels the alarm within a specified time period (between 90 seconds and 3 minutes, depending on the size of the vessel), an alarm will sound in locations where other personnel are usually available.

It is possible to turn off the system but this is off record. Up to our knowledge there are no studies that estimate the extent to which this is actually being done.
6.3.  Infrastructure
There is a system called Vessel Traffic Services (VTS) that continuously monitor all ships and in case there are deviations from a planned trip the ship is contacted to make sure the driver is ok. No evaluations are available.

6.4.  Education and training

6.4.1.  IMO guidance on fatigue mitigation and management
The International Maritime Organization (IMO; www.imo.org) has published guidelines on fatigue and its mitigation and management. IMO member states are invited to bring those guidelines under the attention of all the organisations and parties that have a direct impact on the safety of the ship. These guidelines are composed of nine different modules, each devoted to an interested party; 1. Fatigue, 2. Fatigue and the rating, 3. Fatigue and the ship’s officer, 4. Fatigue and the master, 5. Fatigue and the training institution and management personnel in charge of training, 6. Shipboard fatigue and the owner/operator/manager, 7. Shipboard fatigue and the naval architect/ship designer, 8. Fatigue and the maritime pilot, 9. Fatigue and the tugboat personnel. These guidelines are now about to be revised starting at the February 2015 meeting of IMO’s HTW (human element training and watchkeeping) sub-committee, following a proposal by Australia to do this work, in the light of recent research.

Causes of fatigue are divided into crew-specific factors (e.g., sleep, health, stress, age), management factors (e.g., frequency of port calls, traffic density, weather, workload while in port), ship-specific factors (e.g., design, automation, physical comfort), and environmental factors (e.g., temperature, noise, humidity). Furthermore, it is discussed how fatigue is to be recognised, both in yourself and others based on physical, emotional and mental signs. Concerning fatigue mitigation it is described how to protect yourself from the onset of fatigue, with sleep put forward as the most effective strategy to fight fatigue. The importance of strategic naps, regular well-balanced meals and exercise are also put forward. A separate section deals with mitigating fatigue that is already present, where it is explicitly pointed out that these countermeasures may simply mask the symptoms temporarily rather than eliminating fatigue. The following countermeasures are mentioned:

- change in work routine (anything new and/or different)
- bright light
- cool dry air
- music and other irregular sounds
- caffeine (it is advised against excessive use to maintain proper sleep)
- muscular activity (running, walking, stretching, chewing gum)
- conversation
- controlled naps (20 min advised as the most effective length)

6.4.2. The Nautical Institute
The Nautical Institute has published a few fatigue management tools on their website at http://www.nautinst.org/en/forums/fatigue/fatigue-management-tools.cfm. Those include:

- ISF Watchkeeper software. This software is designed to show whether the working hours of crew are in line with the hours of rest regulations;
- Crew Endurance Management System (CEMS). This is a tool developed by the US Coast Guard and enables companies and crewmembers to manage the occurrence and effects of crew endurance risk factors (such as fatigue) that can lead to human error and performance degradation.
- MARTHA – a new horizon. MARTHA is a prototype fatigue prediction software model, available through the website of Warsash Maritime Academy (UK). Its purpose is to optimise operation and work schedules by minimising average fatigue predictions (http://www.ship-technology.com/features/feature-project-martha-reducing-seafarer-fatigue/)

- Maritime New Zealand – Fatigue management. Maritime New Zealand has collected a wide range of resources to help seafarers and managers in the maritime industry to better understand and manage fatigue. Among links to different sleep(iness) tests and questionnaires is also the booklet “understanding fatigue – get your sleep, reduce your risk”.

6.5. Fatigue risk management

6.5.1. Causes of fatigue

**Traveling to the ship** has been reported to be a main cause of fatigue, where it already occurs before the tour of duty has started (Allen, Wadsworth et al. 2008). A clear example comes from Wadswordth and colleagues who reported that 66% of seafarers reported having no sleep opportunity between traveling to the ship and the beginning of their first work shift. Almost half of this group had been traveling for six hours or more and 20% even 12 hours of more to reach the ship (Wadsworth, Allen et al. 2006).

**Port visits.** Both field studies with diaries (Allen, Wellens et al. 2005) as well as a simulator study (Yilmaz, Başar et al. 2013) have shown that the increased work load associated with port visits contributes to disturbed sleep and increased fatigue. This was confirmed by Hjorth (Hjorth 2008), who even observed a frequent and severe underreporting of working hours in order to stay within the working time limitations.

**Ship design.** That is, noise, vibrations, light conditions (Calhoun 2006, Mets, Baas et al. 2012). Noise on board ships originates from a variety of sources and is hard to avoid. Notorious sources of noise include engines, generators, pumps, and air conditioners (Calhoun 2006, Mets, Baas et al. 2012) and it can result in disrupted and/or less deep sleep which in turn greatly contributes to fatigue. Hence, it is of critical importance that the sleeping quarters on board are located optimally far away from all noise sources on board. Calhoun (2006) even lists possible solutions to reduce noise and thereby minimise fatigue. Attention has also been drawn to the disturbing effect of vibrations and movements of the ship (Wadsworth, Allen et al. 2006, Smith, Allen et al. 2008, Oldenburg, Jensen et al. 2009, Lützhöft, Dahlgren et al. 2010) but no studies have been carried out thus far that correlates these types of physical stress to fatigue levels.

**Working night time** rather than daytime has been shown to be associated with higher levels of fatigue (Leung, Chan et al. 2006, Oldenburg, Hogan et al. 2012), which becomes most obvious during the early morning hours, that is between 4 and 6 AM (Härmä, Partinen et al. 2008, Van Leeuwen, Kircher et al. 2013).

**Abrupt changes in work schedule** have been shown to be a cause of poor sleep in watch keepers. Rotating watch keepers have lower sleep efficiency and higher sleep fragmentation than both fixed watch keepers as well as day workers (Arendt, Middleton et al. 2006). Arendt and colleagues even claim sleep quality to be relatively low in those working at sea compared to onshore workers (Arendt, Middleton et al. 2006).

**Watch systems.** Like shift schedules do ashore, affect sleepiness and fatigue levels at sea. Two-watch systems (like 6 on 6 off) are overall associated with higher levels of fatigue than three-watch systems (such as 4 on 8 off) (Lützhöft, Thorslund et al. 2007, Oldenburg, Hogan et al. 2012). Results in this field study were, however, not significant during the limited total number of participants (n=32). The question of watch system affecting sleep and fatigue was also taken up by Kongsvik and colleagues (Kongsvik, Størkersen et al. 2012) who compared a 6/6 system with a 8/8/4/4 system. Although they
found that sleep quality and sufficiency was better in the 8/8/4/4 system as compared to the 6/6 system, no differences were observed on fatigue parameters. But also within a given watch system, fatigue levels do vary, where peaks are observed, as also described above, in those teams having to work the early morning hours (Härmä, Partinen et al. 2008, Van Leeuwen, Kircher et al. 2013).

**Duration of tour of duty, i.e. time at sea.** Wadsworth and colleagues have shown that fatigue levels upon waking up increases with time at sea, especially during the first week in those with relatively short tours of duty (Wadsworth, Allen et al. 2006). An interesting distinction was made by Smith (Smith 2008) who, in a diary study, observed that the increase in fatigue levels does not apply to day workers who in fact showed reducing sleep problems over the course of their tour of duty. Another interesting result was described by Burke and colleagues in 2009 (Burke, Ellis et al. 2009), who showed that although performance and alertness declined with time on tour, sleep quality actually improved with time on tour.

**Work-related factors.** The questionnaire study of Cardiff University found that several organisational factors such as high job demands and low social support, high job stress, and environmental factors such as physical hazards were associated with elevated levels of fatigue (Smith et al, 2006).

A tool used is the sleep wake predictor that Maritime Administration (Sjöfartsverket) has put on their website (http://www.sjofartsverket.se/upload/Forskningsdb/swp_2008.htm). In this tool sleep and/or work hours can be added in order to raise awareness about where in time the highest fatigue risks are to take place.

### 6.5.2. Prevention and management of fatigue

An earlier literature and internet search by TNO divided countermeasures in reactive and proactive measures (Starren, van Hooff et al. 2008). Reactive countermeasures aim to counteract fatigue as it arises. The reactive countermeasures that were found by Starren and colleagues are in line with those described in the IMO guidelines mentioned previously, whereby napping and strategic caffeine consumption where by far most frequently reported by a group of international maritime experts.

Proactive countermeasures serve to prevent the onset of fatigue and the ones that Starren and colleagues have found here mostly relate to sleep and sleep hygiene, whereby the top-5 consists of 1) a good sleep environment, 2) 7 to 8 hours uninterrupted sleep per night, 3) 2 consecutive nights recovery sleep, 4) adequate sleep, quality of sleep, and 5) obtaining the same amount of continuous sleep as normally at home (Starren, van Hooff et al. 2008)

Ferguson and colleagues observed that unscheduled napping whenever possible resulted in a slow down of the accumulation of sleep debt within marine pilots that usually have extended working hours (Ferguson, Lamond et al. 2008).

No other studies have found that experimentally investigated the efficiency of the different countermeasures as reported by for instance Starren and colleagues (Starren, van Hooff et al. 2008).

### 6.6. Concluding remarks

Although relatively many studies can be found on the topic of sea farers fatigue, their relevance has limitations. The majority of studies found are questionnaire studies in small and/or selected populations dealing with questions like “what do you think would help in preventing fatigue?”. In addition, international maritime experts have come up with and extensive list of, in their view, effective countermeasures (Starren, van Hooff et al. 2008). Although the most frequently reported countermeasures (e.g., napping and coffee) have proven to be successful in other contexts, they have not been systematically investigated in the maritime context.
7. Result - Aviation

7.1. Laws and regulations

The hour of service regulation for pilots determines the flight and duty limitations and minimum rest periods. The regulation is described in the document “Riktlinjer för handläggning av flygarbetstid” (www.transportstyrelsen.se/Global/Regler/Luftfart/ Regulations/riktlinjer_for_flygarbetstid.pdf) and refers to EU-OPS chapter Q (OPS 1.1090-1.1135) and LFS 2008:33. The regulation is more detailed compared to other transport modes (the above mentioned document is 31 pages including attachments) and the operational requirements in aviation are often complex. For example, the regulation of work hour patterns differs depending on the size of the crew and if the flight include crossing multiple time zones. The possibility to perform very long-haul flights requires augmented crews and the opportunity to take in-flight rest (napping during the flight). Traditionally, there have also been differences in implementation of flight crew scheduling recommendations (for example, the International Civil Aviation Organization guidelines) between nations. A brief summary of the guidelines concerning flight and duty limitations is presented in table 1. The hours of service regulation for the other transport modes is also included in the table.

The maximum daily flight duty period is 13 hours, but will be reduced if the duty period includes more than two sectors, or starts within the “window of the circadian low” (WOCL) (defined as the time interval 02.00-05.59h). Hence, a duty period that starts between 21.00h and 03.59h and includes six sectors cannot exceed 9 hours. A duty period with two sectors includes two departures and two landings and the term “sector” can be interpreted as an indicator of the workload. The maximum flight duty period for cabin crew can be extended by one hour.

The flight duty period can be extended by one hour two times per seven-day period. An extended flight duty period that starts between 22.00h and 03.59h can never be longer than 11 hours and 45 minutes and not include more than 2 sectors. Extensions, irrespective of the starting time, are not allowed if the flight duty period includes six sectors or more.

It is also possible to extend the flight duty period if the crew is augmented, which permits in-flight rest. This regulation mainly applies to long haul operations when the flight duty period exceeds 13 hours.

The maximum weekly duty hours are 60 hours in a block of seven consecutive days. In a 28-day period the maximum duty time is 190 hours. The maximum block hours in a calendar year is 900 hours for a pilot. Block time refers to “the time between an aeroplane first moving from its parking place for the purpose of taking off until it comes to rest on the designated parking position and all engines or propellers are stopped”.

The minimum rest before a flight duty period is 12 hours or 10 hours if the rest is taken outside the home base. The minimum weekly rest period is 36 hours including two local nights. Where a flight duty period is planned to use an extension pre and post flight minimum rest is increased by two hours, or by four hours if only the post-flight rest period can be used for extra rest.

The hours of service regulation does not includes limits according to rest breaks within the duty period. However, a meal and drink opportunity must occur if the flight duty period exceeds six hours.

The limits on flight duty and rest periods can be modified if unforeseen events (after check-in) occur. However, the flight duty period may not be increased by more than two hours unless the flight crew is augmented (which permits an increase of 3 hours).

The regulation also includes a paragraph regarding the crew’s responsibility of being fit-for flight. A crew member is not allowed to be on duty if the if he or she feels severe fatigue or drowsiness before a
duty period, or predicts that severe fatigue will occur during the duty that can result in safety risks during the flight.

The strength with the hours of service regulation, regardless transportation mode, is that it prevents severe fatigue by proposing limits of the maximum duration of work shift, length of time awake and weekly working hours. The regulation also ensures minimum opportunities for sleep and recovery (Gander, Hartley et al. 2011). However, despite the limits severe fatigue can occur because regulation does not take circadian regulation into account. For example, high levels of fatigue are likely to be observed during the biological night even though the work shift is below the limits for the duty length and the amount of rest time between work shifts is above the limits. Another problem with hours of service regulation is that it does not address fatigue that accumulates over workdays due to several days with sleep restriction or high workload. A third problem is that the regulation overlooks that sleep during the day will be much shorter than night time sleep, even if the amount of rest time might be longer than the minimum hours (Gander, Hartley et al. 2011). One should also keep in mind that hours of service regulation is based on a “one size fits all” approach, which means that individual differences in tolerance to for example night work cannot be taken into account (Gander, Hartley et al. 2011).

The flight and duty time limitations within EU were recently evaluated by scientific experts of the ECASS group (European Committee for Aircrew Scheduling and Safety). A summary of the evaluation made by ECASS is presented in the Moebus report from 2008 (Moebus-Aviation 2008). The experts identified several problems with the flight time limitations, which may have consequences for fatigue; such as large number of duty hours in a short time, long duty hours, split duty, early morning start times, and night duty. Thus, the current hours of service regulation seems to be a relatively weak barrier against severe fatigue.

The first paragraph of the Swedish work environment act states that the work environment should be designed in such a way that accidents and work-related health problems can be prevented. However, the work environment act refers to factors such as work content, work satisfaction, personal development through work and social climate, and does not address factors that are linked to fatigue such as working times and workload.

7.2. Self-administered countermeasures

The self-administered fatigue countermeasures are often divided into pre-flight, in-flight and post-flight countermeasures (Caldwell, Mallis et al. 2009). The pre-flight fatigue mitigation strategies refer to prophylactic napping before the flight and use of pharmacological countermeasures such as hypnotics (sleep medication), melatonin and modafinil. In general, pharmacological fatigue countermeasures are not a common advice in Europe although non-prescriptive substances such as mild sleep medication and (in some countries) melatonin can probably not be banned. Melatonin is a hormone that can be used for improving adaptation to night work and reducing fatigue at night time (Cajochen, Chellappa et al. 2010). A paper on melatonin concluded that it was not a recommendable strategy for fatigue mitigation among aircrew (Simons and Valk 2009). If melatonin is taken at the wrong (circadian) time, such as early in the day, it is likely to increase fatigue, and most aviation authorities disapprove of the use of melatonin for pilots. Short-acting hypnotics can mitigate sleep loss by increasing sleep length but the target group are mainly military pilots (Caldwell, Mallis et al. 2009). Furthermore, hypnotics are only recommended for short-term use and should not be taken on-day-to-day basis due to potential adverse effects (Morin & Benca, 2012). Modafinil is a psychostimulant drug that can be used to improve wakefulness in patients who suffer of excessive sleepiness. It has also been evaluated in individuals suffering of shift work disorder, which is a diagnosis characterized by excessive sleepiness and severe sleep problems in connection with night work, with good results (Czeisler, Walsh et al. 2005) However, long-term use of modafinil in the working life has as far as we know not been evaluated and there is a concern that the drug may have a potential risk of causing
disturbed sleep, stress and possibly also mental problems (Liira J, Verbeek JH et al. 2014). In EU it is not permitted to use for pilots, it must be related to sleep disorders like narcolepsy. The recommendations regarding pharmacological countermeasures should also refer to cabin crew.

One of the most common in-flight countermeasures is napping. Strategic napping during in-flight rest reduces fatigue and improves alertness although one needs to take sleep inertia into account if on-duty naps are implemented (Hartzler 2014). During long-haul flights in-flight sleep seems to be an efficient fatigue mitigation strategy (Gander, Signal et al. 2013) although sleep quality is lower than sleep on the ground (Signal, Gander et al. 2013). Another relatively effective in-flight fatigue countermeasure is caffeine (Caldwell, Mallis et al. 2009), although it should be pointed out that large amounts of coffee may disrupt sleep taken after the work shift. A break for 15-30 minutes without sleep and coffee has no long-term effects on fatigue. Doing some simple physical activity in the cockpit, such as stretching the legs, is also regarded as a non-effective countermeasure that may only temporarily reduce fatigue.

The post-flight fatigue countermeasures have mainly focused on the length of the layover during long haul operations and the use of hypnotics in order to extend sleep (see discussion above of the pros and cons with sleep medication). It has been shown that short layover length increases fatigue during long-haul operations (Roach, Petrilli et al. 2012). To retain the home-base sleep/wake pattern during layover instead of adapting to local sleep hours may also be a beneficial strategy that reduces fatigue on the return flight (Lowden and Åkerstedt 1998).

7.3. Technical solutions

Commercial aircraft is normally equipped with various warning systems designed to alert the pilot, for example if the aircraft is in immediate danger of flying into the ground, or have a collision with an aircraft. In general, aircraft are not equipped with technological alertness enhancing devices although the need for real-time fatigue detection technology has been realized in recent reports (Caldwell, Mallis et al. 2009). It would probably be possible for pilots to use fatigue detection and warning systems that are commercially available. It should be pointed out that several of the available fatigue detection devices may not be practical for use in a highly restrictive environment such as the flight deck. For example, a flight simulator study showed that PERCLOS, which is a camera-based system that measures eye movements and that have showed promising results in a study on truck drivers, did not counteract sleepiness because the system could not capture the pilots’ eyes during flight operations (Mallis et al. 2004, cited from (Caldwell, Mallis et al. 2009). There is reason to believe that the pilots gaze it not as in car driving focused forward all the time.

The literature review identified a brief paper proposing a system called Optalert to be useful for pilots (Corbett 2009). Optalert utilizes infrared reflectance (IR) to measure eyelid movements. An IR transmitter is attached to a glasses frame, which means that the system is somewhat obtrusive. Optalert has been shown to detect fatigue in car drivers (Johns, Tucker et al. 2007, Ahlström, Andersson et al. 2010), but has not been tested in “real life” flights. (Caldwell, Mallis et al. 2009).

It would also be possible to use bright light exposure in the cockpit as a technological countermeasure. There is strong evidence from laboratory studies that bright light can facilitate circadian adaptation to night work and that light exposure also have an immediate alerting effect (Cajochen, Chellappa et al. 2010). Small-scale tests of blue light in cars have showed promising results (Taillard, Capelli et al. 2012) but the literature review did not find any study on pilots. A review of fatigue countermeasures in aviation suggests that increasing the flight-deck light level during night flights could be done without interfering with flight crew performance and the visual requirements needed (Caldwell, Mallis et al. 2009). A (not peer-reviewed) report presented a small trial that showed that 30 minutes with blue light administered by a portable light box and taken before the flight increased alertness and improved performance on a 5 minute reaction time test (Brown, Schoutens et al. 2014). It is unclear from the report if light exposure had any long-term effects on fatigue.
Another technological fatigue prevention approach is to use off-line fatigue prediction models (Caldwell, Mallis et al. 2009). These tools are often labeled “biomathematical fatigue modeling” in the literature. Fatigue modeling utilizes software tools that predict fatigue during flight, sleep time during off-duty time, and sometimes also performance. Several models have been introduced during the last decade; for example, an extended version of the three-process model of alertness the so-called TPMA (Ingre, Van Leeuwen et al. 2014) the system for aircrew fatigue evaluation called SAFE (Belyavin and Spencer 2004), and the sleep, activity, fatigue, and task effectiveness model SAFTE (Hursh, Redmond et al. 2004). The TPMA has been implemented by the company Jeppesen (that works with computerized flight planning software and management systems) into a fatigue model called the Boeing Alertness Model (BAM) that is tailor-made for aviation (Romig and Klemets 2009). BAM is included in the Jeppesen Crew Alert App available from Apple ITunes store.

The basic components of the fatigue models are (1) a homeostatic process that represents the increase in fatigue with time awake and the recovery that occurs during sleep, and (2) a circadian process that describes the time-of-day variation in fatigue. The TPMA also includes a sleep inertia function that describes the high level of fatigue that occurs in connection with waking-up from sleep. Some models, for example SAFE, estimate the increase in fatigue with time on task. The input data of the fatigue models are working times and in most cases sleep timing.

The development of biomathematical software for detection of severe fatigue is promising but we know very little about the validity of the tools (Dawson, Noy et al. 2011). One of the major concerns refer to individual differences since it is well established that there is a large individual variability in fatigue during night and shift work, and after restricted sleep (Dawson, Noy et al. 2011). It may also be questioned whether it is possible to estimate fatigue without taking work factors such as workload into account. However, a recent paper validated the TPMA in 136 participants working as aircrew and showed robust relationships between subjective sleepiness (measured with the Karolinska Sleepiness Scale, KSS) and predicted sleepiness, in particular for severe sleepiness (Ingre, Van Leeuwen et al. 2014).

The level of automation is high in aviation and there are several safety systems that aim to support the pilot and to reduce the risk of accidents caused by human errors due to for example fatigue and inattention (Amalberti and Hoc 1998). It is not the aim of the present report to make an overview of such systems. High level of automation is likely to increase monotony, and may contribute to unmasking the pilot’s fatigue and workload under certain circumstances (Byrne and Parasuraman 1996, Parasuraman and Riley 1997). However, the safety beneficial effects of the automatic systems are large and in most cases counteract the impaired performance associated with high levels of fatigue. It should be pointed out that there is some concern about a potential deterioration of manual flying skills for pilots who are used to operate flights with high levels of cockpit automation. A recent simulator study found that cognitive skills, such as navigation and failure recognition and diagnosis, are prone to forgetting and may depend on the extent to which pilots follow along when automation is used to fly the aircraft (Casner, Geven et al. 2014).

7.4. Infrastructure

For aviation most infrastructure countermeasures while flying is not a topic were we find research. There might be an issue when it comes to driving the aircraft on ground, to and from gates, even though this is not a commonly mentioned problem.

7.5. Education and training

In a review from 2009 the authors points out education as one of the key recommendations for fatigue countermeasures (Caldwell et al, 2009). The purpose with education is to teach the pilots about the causes and dangers of fatigue and sleepiness, and the importance of adequate sleep. The target groups
for education are not only pilots and crewmembers but also supervisors and schedulers. The key points in an education program are according to Caldwell et al, 2009:

- Fatigue is a physiological problem and not a state that can be overcome by motivation, training and willpower
- There is no one-size-fits-all “magic bullet” solution that can counteract fatigue and sleepiness for every person in every situation
- There are evidence-based fatigue countermeasures that will enhance safety and productivity, but only when they are correctly applied

The education is also regarded as a key component of fatigue risk management system (FRM), which will be discussed in the next paragraph. In agreement with driver fatigue (see chapter on road transportation) the literature review did not find any publication that evaluates whether an educational program reduces fatigue and sleepiness. The literature search did, however, find one recent paper that is linked to education and training. The study evaluated an App (the MORE Energy App) that aimed to reduce fatigue through advising the pilots about feasible and effective fatigue countermeasures (van Drongelen, Boot et al. 2014). The study had a strong design (randomised controlled trial) and a fairly large sample (502 airline pilots employed at KLM) and the results showed reduced self-reported fatigue for the group that used the App. The App is available from Apples iTunes store.

7.6. Fatigue risk management

It is difficult to eliminate severe fatigue with hours of service regulation since there is no link to the basic principles of sleep/wake regulation. Hence, severe fatigue can occur because regulation does not take circadian regulation into account, that fatigue accumulates over workdays due to several days with sleep restriction or high workload, and that the regulation overlooks that sleep during the day will be much shorter than night time sleep, even if the amount of rest time might be longer than the minimum hours (Gander, Hartley et al. 2011).

There has been a strong focus during the last 10 years on alternative approaches to manage fatigue that are linked to safety management (Dawson and McCulloch 2005, Philips and Sagberg 2010). Fatigue risk management (FRM) or as some call it Fatigue risk management systems (FRMS) are an alternative to the use of prescriptive regulation for managing fatigue risks and some countries (for example, New Zealand) has relatively long experience of developing FRM. International Civil Aviation Organisation (ICAO 2011) defines FRM as “a data-driven means of continuously monitoring and managing fatigue-related safety risks, based upon scientific principles and knowledge as well as operational experience that aims to ensure relevant personnel are performing at adequate levels of alertness”. FRM can be described as a four-step process loop: (1) monitor fatigue levels; (2) identify when fatigue is critical for safety risks; (3) assess the associated safety risk; and if necessary (4) implement fatigue mitigation strategies to lower the safety risk; and return to step 1 (Gander et al, 2014).

The essential components of FRM are; (1) a fatigue risk management policy; (2) education and awareness training programmes; (3) a crew fatigue reporting method with feedback; (4) procedures and measures of monitoring fatigue; (5) procedures for reporting, investigating, and recording incidents and errors that have (or may have) a link to fatigue; and (6) processes for managing fatigue-related incidents, for example undertaking interventions that mitigate the fatigue risks (Gander et al, 2011).

The main advantage with FRM is that it contains multiple strategies to reduce the fatigue risk and provides a more flexible and proactive approach to fatigue (Dawson and McCulloch 2005, Gander, Hartley et al. 2011). A possible weakness with FRM is that the employers, employees, and regulators need to have sufficient in-depth understanding of the causes and consequences of fatigue in order to
manage complex safety risks. Lack of expertise can limit the effectiveness of FRM and reduce the company commitment to allocate adequate resources for managing fatigue risks.

Another issue is that there are almost no studies, based on sound scientific methodology, that have evaluated if FRM reduce fatigue risks, improve scheduling, provide the pilots with better sleep opportunities, and decrease the level of severe work-related fatigue. A key determinant for the effectiveness of FRM is how it is implemented in the airlines. A French paper showed that introduction of FRM resulted in increased use of biomathematical fatigue modelling as tool to improve aircrew scheduling, although it is not clear if work-related fatigue was reduced (Cabon, Deharvengt et al. 2012).

Clearly, more research is needed on FRM and aviation fatigue. An expert group recommended further research on topics related to strategies for changing the culture for fatigue self-report and self-monitoring, development of tools for assessing fatigue (based on objective methods) and for improving scheduling (including improved fatigue models that can take individual differences into account), and benchmarking and validation of FRM in real life operations (Weiland, Nesthus et al. 2013).

7.7. Concluding remarks

Fatigue is a significant and well-recognized safety risk in aviation. The literature review shows that the key strategy for fatigue mitigation is thought to be by FRM. However, the effectiveness of FRM is dependent of how it is used in the organizations. A significant reduction of the fatigue-related safety risk probably needs an advanced FRM approach, although it should be pointed out that well-controlled intervention studies on the safety effects of FRM is lacking. To rely on hours of service regulation as the only strategy to manage fatigue will in most cases be insufficient. It is recommended that the prescriptive working hours approach should be combined with some basic FRM – such as using appropriate procedures for monitoring and identifying fatigue risks – in order to safely handle fatigue. The development of future FRM might benefit of using new technology that improves detection and monitoring of fatigue, as well as warning of severe fatigue incidents such as unintentional falling asleep. This conclusion might also be relevant for drivers in other transportation modes.
8. Workshop

With the aim to gather stakeholders view about effective countermeasure per transport mode, but also to rate the most promising ones regardless mode, a workshop was held in Stockholm with a total of 23 participants. They covered all transport modes (see Appendix).

The workshop started with a presentation of the first the main results from the literature review, followed by a detailed description of a review of FRM programs and finally the results from a FRM concept used at a Finnish truck company.

Based on this knowledge the participants, grouped by transport mode, and were asked to identify the most promising countermeasures. In a second stage all identified countermeasures were put on a board and each participant received 5 post-it with the instruction to put the points at those countermeasure they found most promising as generic i.e. regardless transport mode. They had to decide by themselves if they would like to use all 5 point on one alternative or divide them between different alternatives.

Figure 2. The board for the workshop and expert participants.

8.1. Results

In the following section the countermeasures proposed by each group are presented. The frequency of post-it notes for most promising countermeasure regardless transport mode are presented in brackets behind.

Road

- More inspections to make sure that hour of service regulations are followed. The risk to be caught in case of violations seems to be rather low.
- The importance of naps (4)
  - Inform about the effectiveness
  - Education to increase the effect of sleepiness and what to consider in order to avoid it.
  - Clarify what stakeholder that is responsible to provide the information: the Transport administration or the Transport Agency?
- Special focus on women?
- Flexible regulatory fees. If a company follows the regulations the fee should be reduced.
- More and safer rest stops
- Regulations with fewer hours to drive during nighttime – a new law is required. (1)
- Regulations about driving time and rest time also for private drivers - not only for professionals (1)
Rail

- Barriers ATC/ATP/ERTMS
- There is a need for a safety culture

- Education (8)
  - When is it dangerous
  - Culture
  - Sleep

- Camera surveillance

- Schedules (7)
  - Clock wise rotation
  - Rest period
  - Driving time
  - Variation

- Fit for drive (possible to take yourself out of the shift (3)

- Ergonomic variation (sit/stand)

- Simulator training (4)

- Health (1)
  - Wellness
  - Weight
  - Food
  - Exercise

- Create good opportunities for a nap (nigh sleep, day/night)

- Ergonomic in the cabin (3)
  - Light
  - Heat

- Coffee

- Reporting deviations (1)

Sea

- Ship owners' liability for creating good conditions (3)
- The class (education)
- Schedules (systems for watch keeping) (6/6, 4/8, 12/12)
- Reporting (4)
- Checklists and Procedures (2)
- Alarm
- Work environment (3)

Aviation

- Influence on the schedule (3)
- Sleep opportunity (1)
- Just culture 5(14)
- Education
- Nap (8)
- Caffeine
- Team monitoring

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A just culture has been defined as a culture in which front line operators and others are not punished for actions, omissions or decisions taken by them that are commensurate with their experience and training, but where gross negligence, wilful violations and destructive acts are not tolerated. Source: Eurocontrol
Most promising countermeasure regardless transport mode were:

- "Juste culture"
- Education
- Nap
- Schedules taking into account human limitations
9. Discussion

9.1. Laws and regulations

All transport modes suffer from the fact that it is not possible to measure the absolute level of sleepiness in an individual either in real time or after a safety-critical situation. Consequently it will at no point be possible to provide direct and objective proof that sleepiness or fatigue has been a contributing factor in a crash or to a dangerous situation (Anund 2013). Even though this is the case regulations to avoid dangerous driver fatigue, both among private drivers and professional, is of major importance while waiting for new solutions to find biomarkers or other clear indicators for the level of sleepiness.

One way to indirectly counteract fatigue in relation to professional drivers working is through hours of service (HoS) regulations, see Table 1. The table show that there are differences in the requirements depending on type of operation. For example time of the day is not consider for road transportation and adults on sea, but for rail and aviation. Another example is that no one consider time slept before the shift. For all transportation modes there are regulations in relation to the right to have a driving licence. For example, from 2012 in road transportation it is mandatory with medical certificates in case the driver suffers from diseases that may impair driving performance. For rail medical requirements state that a train-driver should not suffer from any medical conditions that may lead to reduced attention, wakefulness, judgment or concentration. However, it is unclear how to judge whether a person is affected by the disease in a way that will increase the risk of sleepiness while driving. This is an area with needs for tools and recommendations in order to support the medical doctors, but also to guarantee an evidence-based judgment with equal treatment of all patients.

Table 1. Key components of hours of service regulations in the different transport modes

<table>
<thead>
<tr>
<th></th>
<th>Road</th>
<th>Rail</th>
<th>Sea</th>
<th>Aviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum length of work shift</td>
<td>9 hours driving per day (2 times a week you may drive 10 hours).</td>
<td>14 hours depending on type of train: cargo 13h, commuter train 9h.</td>
<td>14 hours</td>
<td>13 hours (can be increased with 1 hour 2 days/week).</td>
</tr>
<tr>
<td>Do regulation take “time-of- day” into account?</td>
<td>No</td>
<td>Cross-border trains: 9 hours (8 hours during night). National trains is regulated by collective agreements, at least 62 exists. See also maximum weekly hours.</td>
<td>No, only when aged 18 or younger.</td>
<td>Yes, the length of the work shift is reduced with 0.5-2 hours if the shift starts between 02.00-05.59h</td>
</tr>
<tr>
<td>Do regulation take workload into account?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes, the length of the work shift is reduced with 0.5-2 hours if more than 2 sectors* is included in the work shift</td>
</tr>
<tr>
<td>Maximum weekly working hours</td>
<td>56 hours per week</td>
<td>38h/36h/34h, depending on if it is night and weekend shifts</td>
<td>72 hours</td>
<td>60 hours (190 hours/28 day period)</td>
</tr>
</tbody>
</table>
### Table 1. Recommended rest times and minimum rest periods

<table>
<thead>
<tr>
<th>Road</th>
<th>Rail</th>
<th>Sea</th>
<th>Aviation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Minimum rest time between shifts</strong></td>
<td>During a 24 hours period (30 hours if you are more than one driver) you need to rest at least 11 hours (normal rest) or 9 hours (reduce rest).</td>
<td>Cross boarder trains: 12 hours at the normal residence of the driver and at least 8 consecutive hours if taken away from home. National trains is regulated by collective agreements.</td>
<td>6 hours of rest at least once per 24-hour period.</td>
</tr>
<tr>
<td><strong>Minimum weekly rest</strong></td>
<td>At least 45 hours (possible to reduce to 24 hours with a compensation within four weeks)</td>
<td>National trains is regulated by collective agreements.</td>
<td>77 hours</td>
</tr>
<tr>
<td><strong>Maximum work length until a break</strong></td>
<td>4.5 hours</td>
<td>6–8 hours and there is a need for 30 minutes break. &gt; 8h the break should be 45 minutes</td>
<td>No break regulations.</td>
</tr>
</tbody>
</table>

*2 sectors=a flight duty that includes two departures and two landings (i.e., two flights)*

It is important to be aware of that legalisation for road transport and sea only consider professional drivers and that regulations for private drivers are not existing.

### 9.1.1. The design of the shift schedule is important

The design of the shift schedule plays a key role for the level of fatigue and sleep loss during shift and night work (Sallinen and Kecklund 2010). According to theories of sleep and circadian regulation a “fatigue friendly” schedule should minimize circadian disruptions and minimize accumulating sleep loss over a single shift and a shift cycle. It is also important to have sufficient time for recovery during days off in order to be fully rested when the next work period starts.

There is no “one-size-fits-all” shift schedule that would be optimal for all transport modes. The operational requirements of the companies differ depending if it is road, rail, sea or aviation transportation. However, irrespectively of the operational context a shift schedule includes a number of components that can be adapted to meet different requirements in an optimal manner. A key recommendation is to avoid compressed working hours, characterized by many consecutive work days, short off-duty (rest) time or long work shifts. A more specific description of the organizational elements of a shift system of greatest importance to sleep and sleepiness are listed in table 2.

### Table 2. Recommendations of shift scheduling

<table>
<thead>
<tr>
<th>Shift characteristics</th>
<th>Recommendation</th>
</tr>
</thead>
</table>
| The duration and timing of shifts | • Shifts longer than 8 hours should be avoided if the work task is safety critical, have a high workload, and are carried out during night time  
• Daytime shifts up to 12 hours could be acceptable if the driver/operator gets sufficient rest breaks and if workload is not too high  
• If possible, try to avoid early (start time before 06h) morning shifts |

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<table>
<thead>
<tr>
<th>Shift characteristics</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• The weekly working hours should not exceed 48 hours unless unforeseen events (for example, delays due to road work, technical errors etc.) occurs</td>
</tr>
<tr>
<td>Number of consecutive shifts</td>
<td>The maximum number of consecutive work days are six but should be reduced if the work shifts:</td>
</tr>
<tr>
<td></td>
<td>• Are longer than 8 hours</td>
</tr>
<tr>
<td></td>
<td>• If the workload is high</td>
</tr>
<tr>
<td></td>
<td>• If the rest time between shifts are insufficient</td>
</tr>
<tr>
<td></td>
<td>• If the shift sequence involves night and early morning work</td>
</tr>
<tr>
<td>The distribution of days off in the schedule</td>
<td>• The days off should be spread out in the shift schedule to avoid accumulation of fatigue and sleep loss</td>
</tr>
<tr>
<td>The length of off duty time between two consecutive shifts and work cycles</td>
<td>• At least 11 hours of off duty time between work shifts are needed to get adequate recovery. In practice this means 15 to 16 hours in order to get a good balance between work, social needs and sleep/recovery</td>
</tr>
<tr>
<td></td>
<td>• At least 2 days off (including 2 nights) is needed for the driver to be well-rested before the next work cycle starts.</td>
</tr>
<tr>
<td></td>
<td>• The need for recovery time between work cycles increases with 1 or 2 days if the work shifts included several night shifts or if the work shifts are extended to over 12 hours</td>
</tr>
<tr>
<td>Rotating shifts or permanent (fixed) shifts?</td>
<td>• In cases with 24-hour operations a rotating shift system results in less circadian disruption and reduces the risk of accumulated sleep loss,</td>
</tr>
<tr>
<td></td>
<td>• Some individuals perceive rotation as difficult and permanent shifts can be preferable if one want's regular sleeping times.</td>
</tr>
<tr>
<td>Speed and direction of rotation</td>
<td>• If the shift schedule is based on rotation it is preferable to have clockwise (day – evening - night) rotation instead of counterclockwise rotation</td>
</tr>
<tr>
<td></td>
<td>• It is also recommended to have fast rotation, characterized by few (max 3) similar shifts in a row</td>
</tr>
</tbody>
</table>

When the hours of service regulation (see Table 1) for the different transport modes is compared with the shift design criteria it is clear that several of the recommendations for scheduling are not matched by the prescribed working time regulation related to duty length and rest time length. For example, it is possible to work 13 and 14 hours in a row at sea and in aviation, which deviates from the recommendation that a shift should not be longer than 8 hours if work is carried out at nighttime or is safety-critical and if the workload is high. For road transport the length of work shift can be increased up to 13 hours if non-driving tasks (such as cargo loading) are added.

The weekly working hours for the transport modes is also longer than the recommended maximum of 48 hours. The recommendation of 11 hours of off duty time between workdays can occasionally (at least 1-2 times/week) be avoided in all transport modes. Except for aviation, working time regulation does not take workload and circadian low (the time between 24.00h and 05.00h) into account. In aviation, the reduction of the shift length is still rather limited – and it is possible to work 10 hours or more even if the duty period includes working at night or during high workload.

The working time regulations at sea are less strict than for the other modes of transport and it is possible to have very long working hours. However, it is not sure that the long working hours at sea
produce more fatigue than what is observed in the other transport modes. During a several months long voyage at sea the master of the ship and the bridge officers will focus mainly on work, rest and eating. Thus, there are less conflicting social demands from family and friends at sea, which may result in more sleep opportunities and promote napping during off-duty time. On the other hand, the sleep environment at sea might be inferior compared to sleeping at home or in a hotel.

To sum up, despite detailed hours-of-service regulation in all transport modes, it is possible to have compressed work schedules that will result in high levels of fatigue and accumulated sleep loss. This suggests that there is need for fatigue management based on individual, organizational and technological countermeasures even when prescriptive work hour regulation exists.

9.2. Technical solutions

Road transport has emphasized technical solutions as the key fatigue countermeasure. Most of the technical solutions include sensors for detection and prediction of driver fatigue, whereas less attention has been given to what the driver should do when fatigue is detected. Here more focus on warning strategies and human machine interfaces (HMI) is something that is reasonable to recommend, especially since it is well known that fatigued drivers are aware of their impairment, even if they cannot always foresee the sleep onset (Anund and Åkerstedt 2010, Herrmann, Hess et al. 2010). It is also of importance to keep in mind that the warning strategies and HMI need to consider the reason for the detection (May and Baldwin 2009). If the reason for the detection is sleepiness related then the most effective action is sleep. On the other hand if the reason is task related fatigue (under load or overload) other types of countermeasure might be effective.

Technical solutions are available only in exceptional cases in especially transport modes aviation and sea. The available solutions are rather old, don’t use state-of-the-art technology and less innovative compared to what has been developed for car and truck industry. If this is good or bad is difficult to say. One reason for the car manufactures giving priority to technological solutions might be their understanding of the reason for crashes, but also their views of developing safe cars as one important issue to attract customers. In Europe the framework for funding’s (FP7 and Horizon 2020) support innovative technologies with a demand of cost effective sensors, with a high impact in order to increase safety, but also to support an increase of jobs in the EU countries. On conclusion might be that efforts to support such developments also at sea and in aviation might be promising.

There is reason to believe that rail is the transport mode were you most easily can use less innovative solutions like “dead man’s switch” and activation monitoring. Those are not mainly sleepiness detection systems but rather a way to continuously monitoring lack of performance due to driver impairment that for a train driver is seen in lack of response to signals and speed. Another technical support could be to use tachographs in order to make sure that the regulations are followed and to make it possible to track the working hours.

Common for all implementations of technical solutions is the lack of independent evidence based evaluation of their effectiveness. This is an area with major importance for the future, both regarding methodology aspects and realizations.

9.3. Infrastructure

On road the milled rumble strips are the most promising infrastructure countermeasure with a contribution to the reduction of killed and severe injuries in single vehicle crashes with 30 % on motorways and 14% on 2 lane rural road with the rumble strips in the centre of the road. Infrastructure solutions of importance is also those that make it possible for drivers, especially on road, to stop for a break. There are only a few studies on these aspects even though there are knowledge of the effectiveness of a rest areas (Reyner, Flately et al. 2006). For the professional drivers on road it is essential to provide safe and comfortable rest areas. For bus drivers working split shift it has been seen
that the possibility for a nap is important in order to stay alert especially during the second part of the drive (Anund, Kecklund et al. 2014). For drivers of train, ships and air crafts it is not consider to stop in case of sleepiness.

On rail the ATC or ATP system might be the most relevant ones to mention. Those are well established systems and not primary addressed to driver fatigue. ATC/ATP keep track on the drivers capability to maintain correct speed and to handle stop signals. If the train driver is driving too fast or is passing a signal at danger, the system will initiate an emergency brake to avoid for example a collision or other types of accidents.

9.4. Education and training

The purpose of education as a “stand alone” countermeasure is to increase the knowledge of fatigue causes, risks and countermeasures among drivers. The literature review showed that education is rarely evaluated, although one may assume that a few hours of education probably have a limited impact on drivers’ attitudes and especially to their behaviour to in relation to driver fatigue. Furthermore, there may be other factors such as high workload that prevents the driver from taking appropriate action, for example napping, when severe fatigue occurs.

Education and training is also a very heterogeneous concept that may vary from a short 30-minute lecture every year to a several days long, well-structured and professional education program. However, education and training is a key component in Fatigue management programs.

Even though actions like education are easily understood as an important step towards improved safety, they are not seen as a single solution to the problem of driver fatigue and the effectiveness is highly dependent on the content included. As mentioned before, there are several steps to take requiring knowledge among drivers in order to avoid an increased risk due to fatigue. This needs to be considered in order to receive results. The effectiveness of education and training needs to be evaluated.

9.5. Fatigue risk management

Just as for education and training FRM are seldom evaluated (Philips and Sagberg 2010). There are several approaches and most of them are more general than specific for a transport mode. They often include education, schedules / work restrictions and recommendations for shift work. In the review from 2010 (Philips and Sagberg 2010) it was concluded that evaluations of their effectiveness is lacking, even though there is a strong evidence base supporting the principles of FRM (Gander, Hartley et al. 2011).

The implementation of FRM shifts the locus of responsibility for safety away from the regulator towards companies and individuals, and requires changes in traditional roles (Gander, Hartley et al. 2011) and organizational, ethnic, and national culture need to be considered. This research group also underline that “it is vital that regulators, employer, and employees have an understanding of the causes and consequences of fatigue that is sufficient for them to meet their responsibilities in relation to FRM”

Since Hours of Service regulations is not primarily written to support alert drivers, rather to assure fair competition between companies, the shift towards FRM is a promising step that handles the limitation related to managing fatigue by regulation only. It is important that evaluations of the concept FRM is done in order to guarantee that the system contribute to less stress for the drivers and that all involved actors seriously understand the aim and role of FRM and put effort to also evaluate the effectiveness. This also include a fair safety culture at the company with a “just culture” to report driver impairments and the need for support in case a person for example experience sleepiness or impaired performance due to fatigue. This was the countermeasure that was rated as most promising countermeasure regardless modes of transportation in the workshop.
It may also be noted that FRM models may be less feasible countermeasure in small companies (e.g., fewer than 10 people) than in bigger companies where occupational health and safety experts are more involved and present. In fact, there is need to develop FRM also applicable to smaller transport companies.

In order to stop driving while feeling fatigued the company should have fatigue risk management policy that clearly state what to do in this kind of situation. Thus it would not be only the driver who makes the decision and is responsible for its possible consequences.

9.6. Experts opinion about promising countermeasures

At the workshop with experts the most promising countermeasures regardless transport mode were:

- "Just culture"
- Education
- Nap
- Schedules taking into account the humans limitations

Just culture is a concept that is used especially in aviation. This is an important factor in the safety culture, however there are no scientific papers describing its effect and to what degree this custom is working in practice. However, if the management of a company work support a fair safety climate a just culture will follow. Both evaluations to understand the reality of just culture in aviation, but also evaluations to see if it is possible to work towards also in other transport modes are of interest.

Education was also rated high. It is easily understood that this is a natural countermeasure to propose at a first, since the starting point needs to be that the driver has knowledge about driver fatigue, the risk and how to be prepared. This is however not the same as the knowledge received will decrease the number of fatigue drivers on road, rail, see and in air. Increased knowledge is not per see the same as in improved behavior, at least not when it comes to car drivers and specific education about risky driving (Forward, Wallen-Warner et al. 2010). Further knowledge to understand the relationship between increased knowledge and improved behavior in the area of fatigue in different transport modes are important to gain. There is reason to believe that curricula should be developed in a way that provide not only higher competence but also a greater insight of the dangerous situation it might call, that in a second step influence the drivers behavior towards more safe decisions and behavior. There is also a need to discuss to whom the education should be targeted (drivers, dispatchers, foremen, health and safety experts, top managers). In the same way there is need to learn more about if educations should be addressed to novice “drivers” or to those highly experienced.

Nap is when it comes to sleepiness the only effective countermeasure, but of course also useful for task related fatigue (Reyner and Horne 1997). Countermeasures that make it possible for the drivers to nap is successful, this might be rest areas, a place to nap at for professional drivers etc. In a study of bus drivers it was seen that those napping at breaks had less problems to stay alert while driving (Anund, Kecklund et al. 2014). To make the nap happen there is a need not only for time to nap, but also an attractive, safe and secure place for napping. Strategies and evaluations for this is not commonly seen in practice or in the literature.

Finally schedules taking into account the humans capabilities in terms of time of the day, the need for sleep and the need for rest between work is rated high. The regulations today do not normally consider this, especially not when it comes to private car drivers were there are no regulations at all except that you should not drive if you are fatigued. Regardless type of transport mode, the driver behind is a human and there is reason to discuss the arguments for different regulations of hours of service regulations, driving hours and hours for rest. A harmonization’s is most truly possible to do.
10. Conclusion and Recommendations

From a general point of view most evaluations about countermeasures are done for road transportation. Countermeasures like caffeine, nap and blue light has been proven to be effective and it is most truly useful for all humans’ regardless type of operation and might therefor be considered as useful. From a methodology perspective it is more difficult to evaluate the effectiveness of technical solutions, especially if it is not intervening. For FRM and education it is difficult to draw general conclusions since they normally consists of a specific concept and the result depends on how it was done.

In Appendix 2 a table of proven effective / no effect / not evaluated countermeasures are presented. The table should be used carefully. Depending on the transport mode some conclusions and recommendations might be drawn.

Road:

- Driver fatigue and driver sleepiness is a contributing factor to crashes both among private car drivers and professional drivers. Depending on the purpose of the trip and the reason for being fatigue, different countermeasures might be regarded.
- From a professional drivers point of view a holistic approach including fair schedules, education, technical devices for support and control, time and room for naps, but also a just culture are important. In addition issues related to occupational health services improvements, as in aviation, might be useful. The medical control each 5 year after the age of 40 is one opportunity were issues addressed to obesity, smoking, alcohol consumption and the importance of healthy sleep routines could be checked and informed about. Even though the individuals are responsible for driving alert the management of the companies is of importance to make sure the conditions are reasonable. ISO 39001 might be a useful tool for driver fatigue management.
- From a private car driver point of view an increased understanding of the risk of driving fatigue is important, but also to make sure there are rest areas to stop at. Here future driver support system might be helpful to make the driver more aware of the situation and to guide them towards an effective countermeasure. More efforts should be put on the convincing strategies than on the detection it-self. It should be underlined that without evidence based evaluations it is very difficult to understand what and how to a successful system should be design. Methods for evaluations and evaluations of driver support systems address to driver impairments is important for the future.

Rail:

- The present work situation for Swedish train drivers is not well-documented. The TRAIN project that aimed at investigating train drivers’ working conditions were conducted more than ten years ago and since then the railroad industry has changed a great deal due to the deregulations. Even though there is an understanding that factors like night-time driving, irregular working hours, sedentary work exist in rail transportation, the prevalence and the effect of them on the operator performance is not clear. Knowledge are needed in order to identify concrete actions to mitigate operator fatigue, such as development and testing of FRM for this sector.
- It is thus recommended to investigate the prevalence of fatigue and identifying the major causes of fatigue in today’s railroad industry, in order to suggest effective and relevant countermeasures.
- Technical systems such as systems based on the “dead man’s principle” and ATC/ATP systems are probably rather effective in mitigating or counteracting the effects of driver
fatigue, but they will however not counteract fatigue. In order to reduce fatigue, scheduling is probably one of the most promising countermeasures. There is however a lack of evaluations of the effects of scheduling as well as of other countermeasures for train drivers.

Sea:

- Many aspects related to seafarer fatigue are not in the hands of the individual seafarer. Rather it is support from the company that is nowadays considered to be a limiting factor. Therefore, much of the training and recommendations should be directed towards the management as well
- The most important countermeasure, sleep, can sometimes be difficult to obtain due to unforeseen events like harsh weather
- The port visits put an enormous burden on the seafarer. Not only is workload strongly increased during such a period, also the noisy loading and offloading the ship makes proper rest difficult to obtain and will increase the risk of fatigue.

Aviation:

- Fatigue is a significant and well-recognized safety risk in aviation
- The key strategy for fatigue mitigation is based on FRM. However, the effectiveness of FRM is dependent of how it is used in the organizations. There is a need for well-controlled intervention studies on the safety effects of FRM
- Another approach is to combine hours-of-service regulation with basic FRM – such as using appropriate procedures for monitoring and identifying fatigue risks, and education of how to mitigate fatigue
- The development of future FRM might benefit of using new technology that improves detection, monitoring and prediction of fatigue, as well as warning of severe fatigue events such as unintentional falling asleep
References


Philips, R. (2014). What is fatigue and how does it affect the safety performance of human transport operators?


Van Leeuwen, W., A. Kircher and A. Dahlgren (2013). "Sleep, sleepiness, and neurobehavioral performance while on watch in a simulated 4 hours on/8 hours off maritime watch system" Chronobiology International


Appendix 1

Venue: Dalarnas hus, Stockholm
Date: 2014-10-20

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## Appendix 2.

<table>
<thead>
<tr>
<th>Countermeasure</th>
<th>+ Positive effect</th>
<th>0 No effect</th>
<th>? Uncertain</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Road</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Law and regulations</td>
<td></td>
<td></td>
<td></td>
<td>Working hours, Driving hours</td>
</tr>
<tr>
<td>Self-administrative</td>
<td>Caffeine intake, energy drink, and nap</td>
<td>Open window, radio, singing etc.</td>
<td></td>
<td>It is not fully known, there might be a risk that 4.5 hours of driving night time is too long. The focus should be on rest time in relation to circadian regulation, which determines the possibility to obtain adequate sleep and recovery.</td>
</tr>
<tr>
<td>Technical solutions</td>
<td>Blue light</td>
<td>Detection and information /warning or intervention</td>
<td></td>
<td>There might be an effect when the reason behind is task related sleepiness due to under load.</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>Rumble strips, Information about rest area close</td>
<td></td>
<td></td>
<td>Less monotonous road design might be effective, the effect of speed limits are unknown.</td>
</tr>
<tr>
<td>Education/information</td>
<td></td>
<td>Education</td>
<td></td>
<td>Education is expected to be positive but no studies are available</td>
</tr>
<tr>
<td>Fatigue risk management</td>
<td>Theoretical</td>
<td>Practical Scheduling</td>
<td></td>
<td>From a theoretical point of view it is consider effective, but needs evaluations.</td>
</tr>
<tr>
<td><strong>Rail</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Law and regulations</td>
<td></td>
<td>Regulations, Collective agreements</td>
<td></td>
<td>There are no evaluations of the effects of laws and regulations</td>
</tr>
<tr>
<td>Self-administrative</td>
<td></td>
<td></td>
<td></td>
<td>There is no literature on self-administrative countermeasures for train drivers</td>
</tr>
<tr>
<td>Technical solutions</td>
<td>Dead man’s switch, Cognitive tasks, Fatigue monitoring systems</td>
<td></td>
<td></td>
<td>Dead man’s switch may counteract accidents but it will probably not counteract sleepiness. Cognitive tasks and fatigue monitoring systems are not much evaluated.</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>ATC/ATP</td>
<td></td>
<td></td>
<td>ATC/ATP may counteract accidents but it will probably not counteract sleepiness</td>
</tr>
<tr>
<td>Education/information</td>
<td>Education/training</td>
<td></td>
<td></td>
<td>There are no evaluations of the effects of education and training</td>
</tr>
<tr>
<td>Fatigue risk management</td>
<td>Scheduling</td>
<td></td>
<td></td>
<td>There is a lack of controlled intervention studies on shift systems</td>
</tr>
<tr>
<td>Sea</td>
<td>Countermeasure</td>
<td>+ Positive effect</td>
<td>0 No effect</td>
<td>? Uncertain</td>
</tr>
<tr>
<td>-----</td>
<td>-----------------------------</td>
<td>-------------------</td>
<td>-------------</td>
<td>-------------</td>
</tr>
<tr>
<td></td>
<td>Law and regulations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Self-administrative</td>
<td>Light, cool dry air, music, irregular sounds, caffeine, muscular activity, conversation, napping</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Technical solutions</td>
<td>BNWAS</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Infrastructure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Education/information</td>
<td>IMO guidance etc.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fatigue risk management</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air</td>
<td>Countermeasure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Law and regulations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Self-administrative</td>
<td>For example, napping and drinking coffee</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Technical solutions</td>
<td>Various safety systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Infrastructure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Education/information</td>
<td>Education, training</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fatigue risk management</td>
<td>FRMS</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Swedish National Road and Transport Research Institute (VTI), is an independent and internationally prominent research institute in the transport sector. Its principal task is to conduct research and development related to infrastructure, traffic and transport. The institute holds the quality management systems certificate ISO 9001 and the environmental management systems certificate ISO 14001. Some of its test methods are also certified by Swedac. VTI has about 200 employees and is located in Linköping (head office), Stockholm, Gothenburg, Borlänge and Lund.