



Fatigue 2018



CONTENTS

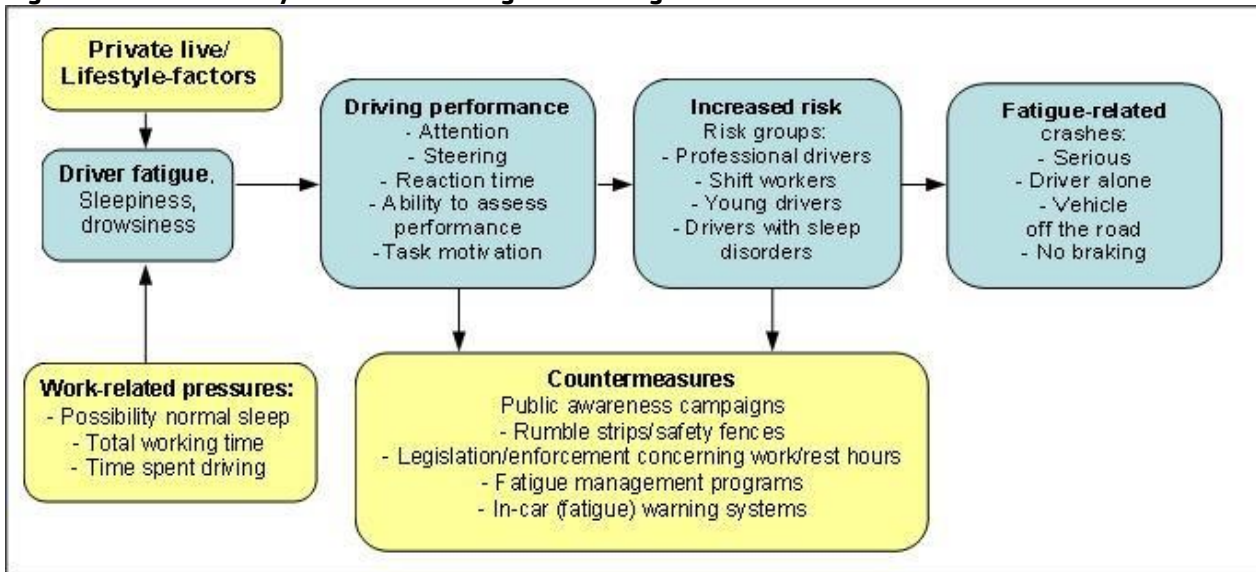
1	<i>Overview</i>	4
2	<i>Introduction</i>	5
2.1	What is fatigue?	6
2.2	Physiological components	6
2.3	Psychological components	6
2.4	Progression of fatigue	7
2.5	Conclusions	7
3	<i>What causes driver fatigue?</i>	8
3.1	Lack of sleep or poor sleep	8
3.2	Internal body clock	8
3.3	Time-on-task	8
3.4	Monotonous tasks	9
3.5	Individual characteristics including medical conditions	9
3.6	Conclusions	10
4	<i>Effects of fatigue on driving</i>	11
4.1	Driving behaviour	11
4.1.1	Steering	11
4.1.2	Speed choice	13
4.1.3	Following behaviour	13
4.2	Driver fatigue compared to drinking-related impairment	13
4.3	Compensatory strategies	14
4.4	'Driving without awareness'	15
4.5	Individual differences	16
4.6	Why do drivers keep driving despite feeling fatigued?	17
4.7	Conclusions	18
5	<i>Prevalence of fatigued driving</i>	18
5.1	Private drivers	18
5.2	Young drivers	20
5.3	Professional drivers	20
5.4	Shift workers	21
5.5	Conclusions	22
6	<i>Fatigue and road crashes</i>	22
6.1	How to recognize a fatigue-related crash?	22
6.2	Frequency of fatigue-related crashes	23
6.2.1	Police records	23
6.2.2	Questionnaire studies	23

Fatigue

6.2.3	Naturalistic observation study	24
6.2.4	In depth crash investigation	25
6.3	Fatigue and crash risk	26
6.3.1	How dangerous is fatigued driving?	26
6.3.2	Combination of factors	28
6.4	Conclusions	28
7	<i>Risk groups</i>	29
7.1	Young drivers	29
7.2	Professional truck drivers	30
7.3	Taxi drivers	31
7.4	Shift workers	32
7.5	Drivers with medical conditions	32
7.6	Conclusions	34
8	<i>Countermeasures</i>	34
8.1	Publicity campaigns	34
8.2	Road infrastructure measures	36
8.3	Technological approaches	36
8.4	Vehicle-based detection and warning devices	37
8.5	Legislation and enforcement	39
8.6	New possibilities for enforcement	43
8.7	Fatigue management programs	44
8.8	Specific company management interventions	47
8.9	Need for further knowledge on countermeasures	47
8.10	Conclusions	48
	<i>References</i>	49

1 Overview

Figure 1: Outline of key issues concerning driver fatigue.



Many definitions are used for fatigue in the literature. The concepts of “fatigue”, “sleepiness” and “drowsiness” are often used interchangeably. Sleepiness can be defined as the neuro- biological need to sleep, resulting from physiological wake and sleep drives. Fatigue has been, from the beginning, associated with physical labour or, in modern terms, task performance. Although the causes of fatigue and sleepiness may be different their effects are very much the same, namely a decrease in mental and physical performance capacity.

The most important general factors that cause fatigue are lack of sleep, bad quality sleep and sleep demands induced by the internal body clock. Apart from these general factors, prolonged driving (time-on-task) can increase driver fatigue especially when drivers do not take sufficient rest breaks. For specific groups of drivers, e.g. professional drivers, these general factors often play a more persistent role due to long or irregular work schedules. A small part of the general population (3-5%) has to cope with obstructive sleep apnea, a sleeping disorder which contributes to above average sleepiness.

Fatigue leads to a deterioration of driving performance manifesting itself in slower reaction time, diminished steering performance, reduced ability to keep sufficient headway and increased tendency to mentally withdraw from the driving task. The withdrawal of attention and cognitive processing capacity from the driving task is not a conscious, well-planned decision but a semi-autonomic mental process of which drivers may only be dimly aware. Drivers may try to compensate for the influence of fatigue for instance by increasing the task demands (e.g. driving faster so that a ‘new’ sensation of driving raises adrenaline and attention levels) or by lowering them (e.g. increasing the safety margins by slowing down or using longer headways). However, crashes and observations of driving performance show that compensatory strategies are not sufficient to remove all excess risk.

Survey research world-wide suggests that over half of all private drivers drive while being fatigued or drowsy at least once a year. Amongst young drivers, driving while fatigued is quite common due to lifestyle factors. Adolescents need more sleep than adults; fatigue may affect

youngsters more than adults. Most professional drivers and shift workers have to cope with fatigued driving on a frequent basis due to work-related factors. About half of all professional drivers have less than normal sleep time before a long-distance trip.

Fatigue is a major factor in a large proportion of road crashes (range 10-20%). Several studies suggest that fatigue is associated with increased crash risk. A person who drives after being awake for 17 hours has a risk of crashing equivalent to being at the 0.05 blood alcohol level (i.e. twice the normal risk). The increased risk often results from a combination of biological, lifestyle-related and work-related factors. More scientific evidence is needed concerning the exact quantitative relationship between fatigue and risk.

Driver fatigue countermeasures may be directed at drivers, transport companies, roads or vehicles. Drivers may learn how to prevent driver fatigue by campaigns. Transport companies can introduce special policies to educate drivers and management about the problem. Roads may also be marked with edging or centre lines that provide audio-tactile feedback when crossed. In future, legislation concerning working and rest hours may be further improved and vehicles equipped with devices that detect fatigue-related decreases in driver performance.

2 Introduction

This text provides an introduction to the subject of driver fatigue, its causes, consequences, and possible countermeasures. The first section examines the characteristics of fatigue, its physiological and psychological components, and the progression of fatigue.

The five main causes of fatigue are described as:

- Lack of sleep or poor sleep
- Internal body clock (circadian rhythm)
- Time-on-task (long working hours)
- Monotonous tasks (lack of stimulation)
- Individual characteristics including medical conditions

Information is given on how fatigue affects driving behaviour in general, steering, speed choice, following behaviour and how compensatory strategies to fight off the effects of fatigue are ineffective. This section also explains that the 'driving without awareness' phenomenon should not be confused with driver fatigue and discusses some important individual differences.

Research results are given on the prevalence of fatigued driving among private drivers, young drivers, professional drivers, and shift workers. Descriptions are also given on how to recognise fatigue-related crashes, their frequency and the evidence concerning the relationship between fatigue and risk. The focus is on a range of groups with a higher risk of driver fatigue: young drivers, professional and truck drivers, shift workers and drivers with sleep and breathing disorders.

Finally, potential countermeasures are outlined, such as publicity, infrastructure, in-vehicle detection and warning, legislation and enforcement, fatigue management programs and a consideration of the need for further countermeasures. At the end of each section the main conclusions are summarised.

2.1 What is fatigue?

In the literature many definitions are used for fatigue. The concepts of “fatigue”, “sleepiness” and “drowsiness” are often used interchangeably. Sleepiness is an aspect of fatigue which is perhaps easiest to define. Sleepiness can be defined as the neurobiological need to sleep (NHTSA, 2001), resulting from physiological wake and sleep drives (Johns, 2000).

Fatigue has been, from the beginning, associated with task performance. In addition, fatigue also has a psychological meaning, for example, not having the energy to do anything and a subjectively experienced reluctance to continue with a task (Brown, 1994). Thus, sleepiness is the drive for sleep while fatigue can be seen as a signal from the body that we should end the on-going activity whether it is physical activity, mental activity or just being awake.

Although the causes of fatigue and sleepiness may be different, the effects of sleepiness and fatigue are very much the same, namely a decrease in mental and physical performance capacity.

There are many diverse sources and forms of fatigue as well as many endogenous and exogenous factors that influence its effects and intensity. Therefore, future studies need to use a more comprehensive conceptualization of fatigue in a multidisciplinary research setting (Smolensky et al., 2011).

2.2 Physiological components

Fatigue is associated with physiological changes in brainwave activity, eye movement, head movement, muscle tone and heart rate. With the onset of fatigue, body temperature, heart rate, blood pressure, respiration rate and adrenalin production are lowered. When fatigued, a person may experience micro-sleeps. Micro-sleeps are brief naps that last for approximately four to five seconds. According to a British survey, one in eight drivers reported having had such a micro-sleep in the past year (Brake road safety charity data and press release, 2011).

One of the most valid indexes of alertness in a driver is provided by electroencephalography (EEG) (Lal & Craig, 2001; Lin et al., 2005). The EEG measures wavelengths of different frequencies within the brain. The electrical activity of the brain is classified according to rhythms. These rhythms are defined in terms of frequency bands including delta (0.5-4 Hz), theta (4-7Hz), alpha (8-13Hz) and beta (13-30Hz). Delta waves are present during transition to drowsiness and during sleep. Theta rhythms replace the alpha components at the onset of sleep. Beta waves are associated with increased alertness, arousal and excitement (Lal & Craig, 2001).

2.3 Psychological components

Fatigue affects mood and motivation as well as psychomotor and cognitive functions (Schagen, van, 2003). Fatigue is partly a subjective experience characterized by lack of motivation, feelings of exhaustion, boredom, discomfort, and a disinclination to continue the task at hand. At the cognitive level, studies have linked sleepiness and fatigue to decreases in vigilance (capacity to detect and respond to unpredictable signals or events over a longer period of time), reaction time, memory, psychomotor coordination, information processing and decision making (Lyznicki

et al., 1998; Isnainiyah et al., 2015). Its effects are strongest in those tasks that are monotonous, that have long duration, that demand constant attention and that have low predictability.

The part of fatigue which is psychological in nature has also been called 'mental fatigue' (Lal & Craig, 2001). Mental fatigue is a gradual and cumulative process and is associated with unwillingness to put in effort, reduced efficiency and alertness and impaired mental performance (Grandjean, 1988 as cited in: Lal & Craig, 2001). According to Grandjean (1979) as cited in Lal and Craig (2001), the functional states of a person range from deep sleep, light sleep, drowsy, weary, hardly awake, relaxed, resting, fresh, alert, very alert, stimulated and a state of alarm. In this series, mental fatigue is a functional state, which may result either in sleep or in a relaxed, restful condition.

2.4 Progression of fatigue

The progression of fatigue has been studied using vigilance tasks. A vigilance task is where a user must maintain attention on the task while waiting for and responding to an uncommon, unpredictable event, such as monitoring security cameras or a radar display. With the use of vigilance tasks, fatigue research has shown that periods of normal performance (i.e. seeing signals on time and providing the right response) alternate with short lapses in functioning (i.e. missing signals or responding very late) (Dingens & Kribbs, 1991). A theoretical explanation is that fatigue is not simply a passive process but is the result of an interaction between deactivation processes (e.g. slower functioning; lesser attention) and compensation processes. This means that a person can react when they notice the onset of fatigue, and may compensate for increased fatigue, for instance, by putting in extra mental or physical effort to perform a task. The interaction of on-going fatigue and compensation (extra effort) leads to performance that becomes increasingly variable or unstable. Thus, performance does not simply decrease steadily but with increasing variability and more and faster changes between normal functioning and erratic functioning (Dingens & Kribbs, 1991).

2.5 Conclusions

- Fatigue has a physical and a mental aspect.
- Fatigue is associated with both reduced capacity and motivation to perform.
- Although sleepiness and fatigue may have different causes, their effects on performance and motivation are similar i.e. a decrease in mental and physical functioning.
- When fatigued, drivers may alternate normal functioning with short lapses in performance (i.e. not noticing or responding to signals). The long-term result of fatigue is an increasing variability of performance.

3 What causes driver fatigue?

Knowledge of the causes of driver fatigue is important for deciding on appropriate countermeasures. Brown (1994) identified 5 general causes of fatigue in general and driver fatigue in particular:

- Lack of sleep or poor sleep
- Internal body clock
- Time-on-task
- Monotonous tasks
- Individual characteristics including medical conditions

3.1 Lack of sleep or poor sleep

The average person needs 8 hours sleep every 24-hour cycle. Sleep prior to work is the most prominent factor that influences the waking state and the level of alertness of the driver (Horne, 1992; Berg, Van den & Lanström, 2006). A chronic lack of sleep is the result of not having enough sleep during a long period. An acute lack of sleep can occur after just one night of little or no sleep. If there has been too little sleep during a 24-hour period, it is referred to as a partial, acute lack of sleep. No sleep at all within a 24 hour period is referred to as complete, acute lack of sleep.

Besides the quantity, the quality of sleep is also of great importance. If sleep is regularly interrupted it leads, as is the case of too little sleep, to day-time fatigue. The quality of sleep is influenced by, among other things, sleeping disorders e.g. sleep apnea (a temporary breathing stoppage while sleeping) and narcolepsy (the tendency to suddenly fall asleep). It can also be a side effect of chronic diseases and/or medication or the result of external factors, such as a noisy or unpleasant sleeping environment.

3.2 Internal body clock

Fatigue is linked to the circadian rhythm. The body's circadian rhythm is an internal biological clock. It coordinates the physiological priorities for daily activities, including sleep, body temperature, digestion, performance, and other variables. Therefore, it has a direct effect on alertness, mood, motivation, and performance.

The body's natural cycle or circadian rhythm plays an important role in how fatigue affects people. The brain and the body are so accustomed to the normal body cycle that they resist changes (such as those caused by work-schedules). The human body has a greater need for sleep at certain times in the 24-hour cycle than at other times (approximately between midnight and 4am and, to a lesser extent, 2pm- 4pm). At these moments there is a natural tendency to sleep and, if this cannot be suppressed, a sleepy feeling occurs. Shift work for instance interferes strongly with normal sleep patterns. Pronounced sleepiness is therefore a typical characteristic amongst most shift workers (Åkerstedt, 1995a; 1995b, 1995c).

3.3 Time-on-task

Prolonged activity inevitably leads to physical and mental fatigue. Researchers have related the duration of activity, or the so called time-on-task, to fatigue symptoms. One of the causes of

driver fatigue is the time-on-task, i.e. the time spent driving. The fatigue-inducing effects of prolonged driving may be decreased by taking frequent breaks (Philip et al., 2005). For professional drivers, the relevant time-on-task is better seen as the total working time (including driving time). Professional drivers often perform many more tasks than the job of driving. For professional drivers, long working hours often go together with an early start and reduced sleep.

3.4 Monotonous tasks

A task is monotonous when stimulation is absent or changes are predictable or there is a high level of repetition. Suburban highways where road environment changes are limited and traffic volume is small match this definition. O'Hanlon and Kelly (1977) pointed out that driving on a monotonous road is the equivalent of a vigilance task. Thus, decreases in driver vigilance are an expression of fatigue. Thiffault and Bergeron (2003) found that in a monotonous driving situation driver steering wheel movement is greater and more frequent showing that the fatigue effect and effect on driver vigilance caused by a monotonous road situation are relatively large. Driving for relatively long periods in a monotonous driving environment also has a clear negative effect on a driver's peripheral visual field (Rogé et al., 2003).

3.5 Individual characteristics including medical conditions

Individual characteristics such as age, physical condition, use of alcohol etc. also influence how fast drivers get fatigued and how well they can cope with fatigue. For example, older people (70+) and persons with poor physical condition are more susceptible to fatigue.

Changes in sleeping habits accompany the transition from teenager to young adult; teenagers may experience chronic sleep loss which may make them more susceptible to temporary effects of fatigue induced by alcohol, drugs or bad sleep (Groeger, 2006). Alcohol use has a sedating effect but alcohol consumed within an hour of bedtime appears to disrupt the second half of the sleep period (Landolt et al., 1996). Sleep disorders have some particular individual characteristics. In Box 1 sleeping disorders known to affect driving are outlined.

In a study on Australian truck drivers, Meuleners et al. (2015) investigated the association between obstructive sleep apnea (OSA) and the likelihood of crashes. In this case-control study 100 long-haul heavy vehicle drivers who were involved in a police-reported crash in Western Australia during the study period (cases) were compared with 100 long-haul heavy vehicle drivers recruited from Western Australian truck stops, who were not involved in a crash during the past year (controls). Driver demographics, health, and fatigue-related characteristics were collected using an interviewer administered questionnaire. The study found that OSA occurred more often among truck drivers (42%) than among the general population (5%) After control for several confounding variables, the truck drivers diagnosed with OSA were over three times more likely to be involved in a crash compared to a driver without OSA.

Box 1. Medical conditions in the European population

Scientific knowledge about major fatigue-related medical conditions and driving risk:

Narcolepsy is a rare sleeping disorder affecting about 1 in every 2.000 persons (Ninshino & Kanbayashi, 2005). Sufferers commonly have 'sleep attacks' in which they fall asleep without warning. This often occurs in inappropriate settings and even after a good night's sleep. Narcolepsy has obvious potential hazards for drivers (<http://www.science.org.au/nova/074/074key.htm>). The sleep episode can last between a few seconds and an hour. Possible side-effects of the disorder include hallucinations, temporary paralysis on waking, and cataplexy (loss of muscle control in emotional situations). This disorder is genetically based and can be treated with stimulants and anti-depressants. Legislation concerning narcolepsy and fitness to drive differs among EU countries. For example, in the UK sufferers from narcolepsy are not usually permitted to drive. In many other EU countries specific legislation regarding narcolepsy is lacking. Obstructing sleep apnea is characterised by the restriction of a person's airflow during sleep caused by the closure of the upper airway. People with sleep apnea receive inadequate quantities of oxygen while asleep causing them to wake frequently resulting in broken and less restful sleep. Sufferers are commonly tired during the day and more prone to symptoms of fatigue including 'micro-sleeps' (sleep episodes in inappropriate settings that last a few seconds). Symptoms of sleep apnea may be made worse by the consumption of alcohol and tobacco.

Sleep apnea: Epidemiological data indicate that at least 5 million patients suffer from sleep apnea throughout Europe (Krieger, 2007). This is about 0,7% of the European population. Of course, registered patients are an underestimation of all persons who suffer from this condition. It is estimated that perhaps as much as 5% of a population may actually be affected by it (see: <http://www.science.org.au/nova/074/074key.htm>).

In Europe, there are no uniformly accepted regulations concerning driving licensing and sleep apnea. Many national European licensing authorities make no specific mention of sleep apnea or excessive daytime sleepiness (Krieger, 2007). Sassani et al. (2004) concluded that treating all US drivers suffering from obstructive sleep apnea syndrome with (CPAP) therapy has a favourable cost-benefit ratio. This would cost 3,2 US billion (dollars) and save 980 lives and 11,1 US billion in collision costs annually in the USA.

Source: Smolensy et al., 2011.

3.6 Conclusions

- The most common general factors that cause fatigue are lack of sleep, bad quality sleep and sleep demands induced by the internal body clock.
- Driver fatigue can be either sleep-related or task related on the basis of causal factors contributing to the fatigued state. Certain characteristics of driving, like task demand and duration, can produce task related fatigue in the absence of any sleep related cause.
- Task-related driving fatigue can be put into the sub-categories of active and passive fatigue. Active fatigue is caused by increased task load, high density traffic, poor visibility and the need to complete secondary tasks. Passive fatigue results from lack of stimulation, monotonous driving conditions, extended periods of driving and automated systems.
- Additionally to these general factors, prolonged driving (time-on-task) can increase driver fatigue, especially when drivers do not take sufficient breaks.
- For specific groups of drivers, e.g. professional drivers, these general factors often play a greater role due to long or irregular work schedules.
- For a small part of the general population (a few percent), obstructive sleep apnea contributes to above average daytime sleepiness.
- There are several medical conditions and associated medications that affect fatigue but that have not yet been studied in relation to fatigue-related driving risk.

4 Effects of fatigue on driving

In general, fatigue affects task performance by causing reduced alertness, longer reaction times, memory problems, poorer psychometric coordination, and less efficient information processing (Lyznicki et al., 1998). Fatigue also has an effect on task motivation in that the motivation to carry out a task diminishes, the communication and interaction with the surroundings deteriorates and one gets irritated more quickly and reacts more aggressively towards people and things (Brown, 1994).

Fatigue leads to diminished actual performance and decreased motivation to perform. Not surprisingly, these general effects on task performance are mirrored by similar effects on the driving task. Fatigue has specific consequences for driving behaviour. Drivers may use compensatory strategies to try and ward off effects of fatigue. A separate phenomenon from fatigue – but often linked to it – is ‘driving without awareness’. Finally, it should be borne in mind that there are individual differences in how persons react and cope with fatigue.

4.1 Driving behaviour

For the driver, the main effect of fatigue is a progressive withdrawal of attention from the road and traffic demands leading to impaired driving performance (Brown, 1994). Research has shown that a person who drives after being awake for 17 hours has impaired driving skills comparable to a driver with a 0,05 g/l blood alcohol level. A driver who has gone without sleep for 24 hours has impaired driving skills comparable to a driver with a high BAC of 0,1 g/l (Williamson & Feyer, 2000). The ultimate impairment is falling asleep at the wheel.

Several studies (Dinges, 1995 & Philip et al., 2005) have shown that fatigue influences driving behaviour in specific ways:

- Slower reaction times: fatigue increases the time taken to react in an emergency.
- Reduced vigilance: subjects perform worse in attention-based tasks when sleep-deprived (e.g. a fatigued driver will be slower to notice oncoming hazards, such as roadworks or a railway crossing).
- Reduced information processing: fatigue reduces both the ability to process information and the accuracy of short-term memory (e.g. a fatigued driver may not remember the previous few minutes of driving).

Yang et al. (2009) studied driving performance at different levels of sleep deprivation. It was found that sleep deprivation had a greater effect on rule-based than on skill-based cognitive functions. When drivers were sleep-deprived their performance in responding to unexpected occurrences deteriorated while they were able to continue with routine driving tasks, such as lane tracking, vehicle following and lane changing, unaffected.

4.1.1 Steering

On-the-road studies have indicated that steering performance gradually deteriorates and that performance decreases are correlated with subjective ratings of fatigue (O'Hanlon & Kelley 1977; Riemersma et al., 1977).

In a simulator study, (Hulst, van der, et al., 2001) found that even in a limited 2,5-hour time-span subjective fatigue and sleepiness increased as a function of time on task. The increase of

fatigue and sleepiness was accompanied by an increased aversion to continue driving and a deterioration of steering performance. Interestingly, larger increases of fatigue and sleepiness were associated with larger increases of aversion and a greater deterioration of steering performance. These results suggest that fatigue is accompanied by a decreased motivation to continue with a task.

In a study by Winsum, van (1999), participants had to drive for 3 hours in a driving simulator on a two-lane road outside urban areas. As the drive progressed, steering performance became less flexible and the amplitude of steering corrections increased. Van der Hulst et al. (2001) also found that, after a 2,5-hour drive in a simulator, steering performance deteriorated. Desmond (1998) found that effect of fatigue on steering performance and on lateral position was greater on straight road sections than in road curves. Desmond concludes that tired drivers have more difficulty regulating attention and performance in situations with low task demand (straight road sections) than in situations with high task demands (curves).

Åkerstedt et al. (2005) compared the performance of shift-workers after a normal night's sleep with performance after a normal night shift in a driving simulator. Driving after the night shift was associated with an increased number of occurrences of two wheels outside lane markings and with an increased lateral deviation of the vehicle. Performance after a night shift also led to increased eye closure and increased subjective sleepiness.

In an Australian simulator-study, Williamson et al. (2014) found that participants who rated themselves as sleepy or likely to fall asleep had a more than 9-fold increase in the hazard of crossing a road centerline compared to those who rated themselves as alert.

A Chinese simulator study investigated the effects of fatigue on driving performance under different road geometries (Du et al., 2015). The researchers found that the effects of fatigued driving were larger in curves than in straight sections. Fatigue led to higher speeds but only in curves not on straight sections. Moreover, the radius and the direction of the curves also played a role. As the curves' radii decreased and the direction changed, the participants found it harder to control the steering wheel and maintain a stable lane position. This research into interaction between fatigued driving performance and geometry conditions may help to better detect and define fatigued driving states.

A simulator study by Morris et al. (2015) also focused on driving performance in curves. The study showed that the single best indicator to detect drowsy driving was the lane heading difference metric. This metric indexes the momentary difference between the direction of the participant's vehicle in degrees and the tangential direction of the lane in degrees, i.e. how much to the right or left the vehicle is facing at a particular instant relative to the lane. According to the authors, their methodology allows real world application. The three primary components required for the functional implementation of the proposed system are lane heading data, vehicle heading data, and an analysis system. Lane heading data can be gained using accurate differential global positioning system technology (DGPS) providing feedback to the system based on current vehicle location and direction (heading) of lane. Vehicle heading data can be collected using onboard computers with a directional sensor (heading) based on the vehicles center line, providing feedback to the system based on current vehicle direction. Using this method, a system would use DGPS to detect when a vehicle was nearing a curve and systematically sample the lane heading along with the current vehicle heading. Once the vehicle completed the curve, the

system would run the statistical model. If the value (variability) was considered to be beyond a set cutoff, then a separate system for alerting the driver could be initiated.

4.1.2 Speed choice

A German simulator study showed that participants drive faster the longer they perform the driving task (Hargutt et al., 2000). However, driving faster did not diminish general driving performance. The researchers considered this as evidence for the hypothesis that drivers attempt to adapt their attention-level (by changing speed). In other words, by changing speed drivers may change sensory input which may spur the body and mind to put in extra effort to notice and respond to signals from the environment.

In a survey study by Oron-Gilad and Shinar (2000), 12% of military truck drivers said that they drove more slowly when they were fatigued; 14% admitted to having difficulties with estimating their own speed correctly. Riemersma et al. (1977) report that sleepiness is accompanied by reduced muscle force manifesting itself in less force on the accelerator pedal.

4.1.3 Following behaviour

In a study of time-on-task effects on car-following performance, Brookhuis et al. (1994) found that differences between the speed of the following car and the speed of the lead car became larger after 2.5 hours of continuous driving. This indicates that accuracy in following the lead car's speed changes was reduced.

A simulator study (Hulst, van der, et al., 2001) found that participants who became more fatigued during a prolonged drive increased their headway to a greater extent than participants who reported only slight increases of fatigue. This applied less to participants who had to perform the task under time pressure. Time pressure may make the task more challenging and less monotonous thereby sustaining motivation to perform well.

4.2 Driver fatigue compared to drinking-related impairment

Drinking-related impairment has been used as a general reference category to quantify the effects of driver fatigue. Studies have found that moderate sleep deprivation produced impairments at levels similar to those found with moderate alcohol consumption (Williamson & Feyer, 2000; Arnedt et al., 2001). For mean tracking, tracking variability and speed variability 18,5 and 21 hours of wakefulness produced changes of the same magnitude as 0,05 and 0,08% blood alcohol concentration respectively. Alcohol consumption produced changes in speed deviation and off-road occurrences of greater magnitude than the corresponding levels of prolonged wakefulness. While limited to situations in which there is no other traffic present, the findings suggest that impairments in simulated driving are evident even at relatively modest blood alcohol levels and that wakefulness prolonged by as little as 3 hours can produce decreases in the ability to maintain speed and road position as serious as those found at the legal limits of alcohol consumption (Arnedt et al., 2001).

A UK study found that blood alcohol levels below the UK legal driving limit significantly increased fatigue-related impairments in young men, though these drivers were not aware of the effect (Horne et al., 2003). Another study noted that moderate (legally safe) blood alcohol levels markedly worsened fatigue-impaired driving in women. However, women were also more aware

of and better able to judge driving impairments than men which could explain women's lower fatigue-related crash rates (Barrett et al., 2004)

4.3 Compensatory strategies

Prolonged driving is accompanied by a decreased motivation to continue driving and reduced accuracy of lateral and longitudinal vehicle control (Brown, 1994; Hulst, van der, et al., 2001). To a certain extent, motivation, i.e. the investment of extra mental effort, can compensate for the performance-decreasing effects of prolonged driving. However, sustained effort may not be enough because the ability to monitor the efficiency of one's own performance may deteriorate as well as a result of fatigue (Brown, 1995). On the basis of experimental simulator studies, Matthews and Desmond (2002) suggest that task-induced driver fatigue reduces awareness of performance impairment. Moreover, task-fatigued drivers appear to have difficulty mobilising sufficient task-directed effort (i.e. keeping enough attention on the task and responding to signals). This is especially the case when task demands are low. Theoretically, in a fatigued state, performance goals become de-activated, perhaps due to competition from comfort-seeking goals, and thus the drivers loses awareness of performance deterioration. The same authors link sleep-related fatigue with reduced motivation or inability to mobilise compensatory effort following detection of impairment (Matthews & Desmond, 2002).

Under normal circumstances drivers are likely to increase their safety margins when they become fatigued and performance deteriorates (Hulst, van der et al., 2001). When performance is starting to deteriorate, taking frequent breaks may cause recovery of normal performance. A French on-road study showed that a rested, non-professional driver can drive 1.000 km from 9am to 7pm, with three 15 minutes breaks and one 30 minute break, without noticeable decreases in performance (Philip et al., 2005). The study demonstrates that fatigue generated by extensive driving has a limited impact on driving skills in normally rested drivers. In an American study on the effects of rest breaks on commercial driver's crash risk, Chen and Xie (2014) found that two rest breaks are enough for a ten-hour trip, and the length of 30 minutes per rest break is usually adequate. Taking the rest breaks too soon after a trip starts lessens the effectiveness of the break. In a survey study among Colombian truck drivers, Torregroza-Vargas et al. (2014) also found evidence that a larger number of breaks reduced crash risk. Also, crash risk was higher when very short breaks (10-20 minutes) were used instead of breaks lasting 21-30 minutes. A Chinese study by Wang and Pei (2014) looked into the driving performance of commercial coach drivers on prolonged 2 hr to 4 hr drives on Chinese highways. After driving for 2 hours a 15 minute break was sufficient to return attention and reaction abilities and subjective fatigue to normal pre-driving levels. When driving for 3 hours, a 15 minute break was enough to restore reaction time and subjective fatigue, but a 30 minute break was necessary to restore attention and operating abilities. When driving continuously for 4 hours all aspects of driving performance were influenced significantly. A 15 minute rest was enough to restore perception and reaction performance and subjective fatigue to former levels, but a 30 minute break was necessary to restore attention and operating performance.

In a simulator study using professional truck drivers Ronen et al. (2014) found evidence that a combination of compensatory strategies using a rest break and using an energy drink worked best in maintaining a stable driving performance.

In several survey studies the countermeasures used against fatigue by drivers have been examined (Vanlaar et al., 2008; Gershon et al., 2011; Goldenbeld et al., 2011) In a survey among drivers in Ontario a majority of drivers (58,6%) admitted that they occasionally drive while fatigued or drowsy and 14,5% of respondents admitted that they had fallen asleep or “nodded off” while driving during the past year. Nearly 2% were involved in a fatigued or drowsy driving related crash in the past year. Respondents were also asked about measures they take to overcome fatigue or drowsiness. Results indicate that relatively ineffective measures such as opening the window or playing music were the most popular. The most effective preventive measure - taking a rest - was the least popular.

Goldenbeld et al. (2011) undertook a web-based panel survey and contacted 4.900 car drivers. The survey consisted of 67 questions arranged in themes about sleep (including the Epworth Sleepiness Scale), health, work, fatigue in everyday life, amount of driving, fatigue while driving, crashes and near-misses, countermeasures (use and effectiveness) and background. About half of the respondents (55%) reported that they had driven while being a little tired in the last 12 months. A quarter of the respondents reported that they had been so tired that they had trouble staying awake at least once in the past year. 10% of respondents indicated that they had fallen asleep or had almost fallen asleep behind the wheel at least once in the past year.

Goldenbeld et al. (2011) found that individual vulnerability to daily sleepiness, as measured by the Epworth scale, was the strongest predictor of falling asleep behind the wheel. For drivers who reported a small possibility of falling asleep in everyday (non-driving) situations the odds of doing so behind the wheel were a factor 4,5 greater compared to drivers that reported no possibility of falling asleep in everyday situations.

In another research survey on individual countermeasures, Gershon et al. (2010) compared countermeasures of professional and non-professional drivers at the strategic, tactical and operational levels of the driving task. Listening to the radio and opening the window were the most frequently used and also perceived as highly effective coping behaviours by both groups of drivers. Talking on a mobile phone or with a passenger were more frequently used by non-professional drivers whereas, planning rest stops ahead, stopping for a short nap and drinking coffee were more frequently used by professional drivers. These methods were also perceived as more effective by professional than by the non-professional drivers and their usage frequency highly correlated with perceived effectiveness.

Non-professional drivers counteract fatigue only at the tactical/manoeuvring level. Hence, they tend to adopt methods that help them pass the time and reduce their feelings of boredom but which do not require advance preparations or adjustments in driving. In contrast, professional drivers counteract fatigue at the strategic/planning level of driving and use a much larger repertoire of coping-behaviours.

4.4 ‘Driving without awareness’

A phenomenon which is sometimes confused with driver fatigue, but which is quite different is ‘driving without awareness’ (DWA). Drivers may demonstrate low attention levels during driving without being fatigued by time on task, lack of sleep, poor quality sleep or time of day. The driver performs in a state in which no active attention is paid to the driving task as if an ‘autopilot’ is operating. At a certain moment, the driver ‘awakes’ and cannot remember the foregoing driving

period. This phenomenon has been labelled as 'Driving without awareness' and also as 'Highway hypnosis' or 'Driving without attention mode' (DWAM). Brown (1994) links this phenomenon to the monotony of the driving task or situations that presents the same and predictable demands on visual tasks. During DWA the eyes stay open in contrast to micro-sleep during which the eyes are closed for at least 2 seconds. In Box 3, the findings of one study on driving without awareness are outlined.

Box 3. Driving without awareness, monotony and driving errors

Karrer et al. (2005) asked a representative sample of 83 German drivers to perform a monotonous driving task on a motorway for 2 hours. Trained observers registered the occurrence of DWA as being indicated by one or more of the following symptoms:

- The driver starts staring into space
- The driver starts staring and head moves upwards or downwards
- The driver's eyes commence a rolling movement
- The driver starts squinting

During the drive, the EEG (duration and frequency of alpha waves), eye jumps (saccades) and the frequency of eye blinks were measured. Traffic errors were also measured (mainly crossing over edge markings). DWA occurred for 18% of the drivers and relatively more frequently among young male drivers. The 83 participants in total crossed edge markings 260 times. In 33,5% of these cases DWA was present. DWA went together with a decrease in the number of eye jumps and a decrease in the size of the jumps. The higher the frequency of DWA moments, the longer the duration of eye blinks. This last result supports the conclusion that DWA occurs at a low intensity attention level and that this causes more traffic errors to be made.

Source: Karrer et al., 2005

4.5 Individual differences

People differ in the extent to which they get fatigued and in the way they cope with driver fatigue. Investigating driving performance on a 2,25 hour simulator night drive, Verweij and Zaidel (2000) found that persons who were extroverted (assertive, gregarious, excitement seeking) and easily bored, and who had an external locus of control demonstrated more serious driving errors as a result of fatigue.

Thiffault and Bergeron (2003) also found relationships between personality, disposition to driving and fatigue behaviour. In their experiment 56 male drivers were observed on two different road settings (monotonous environment vs. visually diversified scenery). They showed that higher levels of "sensation seeking" and "experience seeking" went together with higher variability of steering wheel movement. In addition, extroverted persons and "high sensation seekers" were more likely to fall asleep at the wheel.

Van Winsum (1999) found that young and elderly drivers became equally tired by a prolonged drive in a simulator. Fatigue had a negative effect on keeping on course which was more pronounced for elderly drivers.

Desmond and Matthews (2009) showed that individual differences in fatigue proneness (as measured by Driver Stress Inventory Fatigue Proneness Scale) were a major predictor of post-drive subjective states in both real and simulated driving and was the best predictor of change in fatigue during driving. The same research showed that individual differences in coping with

fatigue and stress were related to fatigue outcomes. Emotion-focused coping was related to post-drive fatigue and tension.

Di Milia et al. (2011) reviewed the literature pertaining to the association between demographic variables (e.g., age, sex, race, socio-economic status, etc.) and fatigue and, when feasible, crash risk. They also explored their potential influence and interaction with some working arrangements, commuting time, personality characteristics and circadian chronotype. Some of the main findings are set out below:

- Ageing results in a gradual deterioration of physiological, circadian and sleep systems, and the weight of evidence suggests a linear relationship between chronological age and fatigue. The authors qualify this statement in that this seems to apply to blue-collar but not to white-collar workers.
- The literature suggests females recognize fatigue better or are at greater risk of fatigue than males, especially when involved in night shift work, independent of age, whether age is defined chronologically or by experience. The potential consequence of this difference between men and women for road crashes has not yet been established (Di Millia et al., 2011).
- Long commutes, especially when tied to an early morning shift start time, are associated with short recuperative sleep and excessive daytime sleepiness and fatigue (Di Millia et al., 2011).
- Evening chronotypes (owls) tend to have shorter periods of sleep than morning (larks) and intermediate chronotypes and are sleepier in the morning when made to conform to standard daytime work schedules since their preferred bedtime is typically positioned an hour or more after midnight. On the other hand, if allowed to live a schedule that matches their circadian preference, i.e., one that allows awakening late in the morning or even early afternoon, 'owls' show much less fatigue in the hours after awakening and high alertness late into the day and night. 'Larks' in contrast, tend to be very alert in the morning but are prone to sleepiness and fatigue by the early evening.

According to researchers, a better understanding of the role of individual differences is needed to improve our ability to predict fatigue, to better understand the safety implications of fatigue, and to determine the effectiveness of various fatigue countermeasures (citations mentioned in Horrey et al. (2011)).

4.6 Why do drivers keep driving despite feeling fatigued?

The fact that many respondents in survey research report experiences of feeling tired or sleepy behind the wheel and the fact that self-reports of sleepiness are related to self-reported crashes or to driving performance loss (Goldenbeld et al, 2011; Williamson et al, 2014) suggest that most drivers are keenly aware of being sleepy and the risk of possibly falling asleep. The question then is: Why do drivers keep driving when they are aware of their own fatigue and the associated risk?

In Australian, Norwegian and Dutch research it was found that 'wanting to get to one's destination' and 'being close to home' are major motives for drivers to keep driving even though they feel very tired or sleepy (Armstrong et al., 2010; Nordbakke & Sagberg, 2007; Goldenbeld et al., 2011). For example, in the Dutch survey on driving fatigue, wanting to go home and the belief that this destination can be reached without falling asleep were mentioned by 2 of every

5 drivers (Goldenbeld et al., 2011). In the same research it was also found that time factors are significant.

4.7 Conclusions

- Fatigue leads to a deterioration of driving performance manifesting itself in slower reaction time, diminished steering performance, reduced ability to maintain headways and increased tendency to mentally withdraw from the driving task.
- Drivers try to compensate for the influence of fatigue, for instance by either increasing the task demands (e.g. driving faster) or lowering them (e.g. increasing the safety margins by slowing down or increasing following distances). These are compensatory strategies that drivers select to ward off the mental and physiological effects of fatigue.
- When drivers are well rested and when they take enough breaks during driving, they can drive for a long time without reducing performance. To maintain performance during a 9 to 10 hour drive, 2 breaks of 30 minutes can be effective, provided that they are not taken too soon after the start of the trip.
- One reason compensatory strategies may fail is that during fatigue people lose the ability to appraise their own driving performance. This is especially the case for driving in monotonous road environments.
- A separate, different phenomenon is 'Driving without awareness' which can be induced by the monotony of the driving environment. Driving without awareness can occur without the driver being particularly tired.

5 Prevalence of fatigued driving

In modern, 24-hour societies getting enough sleep or rest is not always a high priority but it raises questions such as: 'How many people are so fatigued that they feel it interferes with their functioning' and 'How many people drive while they are fatigued'. Survey research provides information on the extent to which fatigue or sleepiness interferes with normal functioning in everyday life. According to the 2002 "Sleep in America" poll nearly two out of every five American adults (37%) report that a few days a month or more they are so sleepy during the day that it interferes with their daily activities; 16% experience this level of daytime sleepiness a few days per week or more (WB & A, 2002). A comparable survey has not yet been done in the EU.

5.1 Private drivers

Survey research in Canada, Europe and USA indicates that driving while tired or sleepy occurs at least once a year for a large proportion of the population. Table 1 below presents findings from studies in seven countries.

Table 1: Key survey results concerning driver fatigue.

Country	Author(s)	Key fatigue results
Great Britain	Maycock 1997	29% of respondents stated that they “had felt close to falling asleep while driving” in the past year.
Norway	Sagberg, 1999	10% of male drivers and 4% of females reported they had fallen asleep while driving during the last 12 months; 4% of these events resulted in crashes.
USA	National Sleep Foundation 2002-2005	60% of adult drivers and 51% of teenage drivers reported driving whilst feeling drowsy at least once a year; 14% of adults and 15% of teens said they drive while drowsy at least once a week; 37% of adults and 5% of teens said they had fallen asleep at the wheel within the past year.
Ontario	Vanlaar et al., 2008	Nearly 60% of Ontario drivers admitted that they had driven while fatigued at least sometime; 14,5% of Ontario drivers said they actually fell asleep while driving at least once in the past year.
Ireland	Amárach Research, 2009	14% of vehicle drivers have fallen asleep while driving; for those who fell asleep at the wheel, the primary consequence was a startling awakening followed by driving onto the hard shoulder; 2% of those who fell asleep collided with an object; the average length of journey that led to falling asleep at the wheel was 4,5 hours.
Netherlands	Goldenbeld et al., 2011	55% of Dutch drivers reported that they had driven while being a little tired in the last 12 months; 25% reported that they had been so tired that they had trouble staying awake at least once during past year; 10% indicated that they had fallen asleep or almost fallen asleep behind the wheel at least once in the past year.
United Kingdom	Brake road safety Charity, 2011	A poll of 1.000 drivers showed that one in eight drivers had ‘nodded off’ or had a micro-sleep in the past year, that a quarter admitted starting journeys when already feeling tired and that nearly 9 out of 10 (86%) did not follow advice to stop somewhere safe for a nap when feeling tired at the wheel. 1 in 7 respondents reported suffering from a health condition such as sleep apnea that made them tired during the day.

A New Zealand study (Connor et al., 2001) aimed at obtaining reliable estimates of the prevalence of driver sleepiness. A sample of car drivers representative of time spent driving on public roads in a geographically defined region was collected. 588 car drivers and drivers of light vehicles were surveyed at 69 roadside survey sites. From this sample it was estimated that in New Zealand 58,7% of driving was undertaken by men. Most driving was undertaken by drivers with Epworth Sleepiness scores in the normal range. However, a significant minority was undertaken by drivers with one or more characteristics likely to impair alertness. 3,1% had 5 hours of sleep or less in the previous 24 hours and 21,9% had 4 or fewer full nights of sleep in the previous week. 8,1% of those surveyed worked a pattern of shifts likely to interfere with normal sleep. Results also found that 1,6% experienced symptoms associated with sleep apnea. The strength of this study is that it measures sleepiness in drivers in proportion to actual driving time on the roads. Therefore, the study directly measures exposure to the risk of fatigue-related crashes and injuries. Previous studies of driver characteristics or vehicle crashes that have considered exposure to risk have most often used driver-kilometres as the denominator. Although this is highly correlated with driving time it is not identical.

5.2 Young drivers

Driving while fatigued is quite common among young drivers due to lifestyle factors (Harrison, 2006). Adolescents need more sleep than adults but often do not get it. Fatigue can affect young people more than adults (Groeger, 2006). According to the National Sleep Foundation's 2006 "Sleep in America" poll, only 1 in 5 adolescents (20%) gets an optimal amount of sleep in a week and more than half (51%) report having driven while feeling drowsy in the past year.

A survey among young drivers (18-25 years) in Victoria, Australia indicated the following (Harrison, 2006):

- 43% of young drivers had driven in the preceding week when mentally fatigued or sleepy;
- 40% had driven in the preceding week when physically tired or worn out;
- 10% admitted driving after more than 24 hours without sleep in the preceding two weeks;
- 3% admitted to falling asleep while driving in the preceding two weeks.

5.3 Professional drivers

The results of different surveys world-wide (Australia, France, Ireland, Netherlands, USA) show that over 50% of long-haul drivers have at some time almost fallen asleep at the wheel (ETSC, 2001). A survey among Dutch, German, Belgian, Danish and Italian long distance truck drivers provided the following results on fatigued driving (Ouwerkerk, van, et al., 1986):

- 43% sometimes almost fall asleep but have never actually fallen asleep;
- 9% have fallen asleep but never had a crash;
- 7% had a crash caused by falling asleep.

In total, 60% of European truck drivers report having almost falling asleep while driving. Van Ouwerkerk et al. (1987) reports similar figures for USA (64%), Australia (60%) and Ireland (45%).

A Finnish survey (Häkkinen & Summala, 2000a, 2000b) amongst 317 male truck drivers showed that long-distance drivers in particular had to deal regularly with fatigue while driving; over 40% reported falling asleep briefly in the past three months and about 25% reported this to have happened twice during this period. In contrast, only 15% of short-distance truck drivers reported falling asleep briefly behind the wheel in the past 3 months.

In several studies of European professional drivers (both car drivers and truck drivers), it was demonstrated that long-distance driving is often accompanied by reduced sleep duration (Philip et al., 2005):

- In one study of 567 car drivers, 50% had reduced their normal sleep in the 24 hours before departing on a long-distance journey and 10% had no sleep in the 24 hours before being interviewed;
- In another study of 2.197 car drivers, again 50% of drivers had reduced their total sleep time in the 24 hours before the interview compared with their normal (self-reported) sleep time, and 12,5% presented a sleep debt greater than 180 minutes and 2,7% a sleep debt greater than 300 minutes;
- In a study of 227 truck drivers, 12,3% had slept less than 6 hours in the 24 hours prior to the interview and 17,1% had been awake more than 16 hours.

A survey of 573 long-distance truck drivers travelling on New York interstate highways indicated that 47% of the drivers had fallen asleep at the wheel of a truck and 25% had fallen asleep at the wheel in the past year (McCartt et al., 2000).

In a 2011-survey more than 700 Portuguese truck drivers responded to questions on sociodemographic characteristics, work, personal health, sleep habits and accident history over the preceding 5 years (Catarino et al. 2014). More than 8 out of every 10 drivers (86%) reported driving while feeling sleepy and more than one to six drivers (15%) reported to drive while feeling sleepy three or more times a week. The same proportion of drivers (15%) admitted to actually having fallen asleep at the wheel in the past 5 years. Drivers who averaged less than 6 hours of sleep per night had a 3,7 fold increased risk of falling asleep at the wheel and a 2,3 fold higher odds of having had a near-miss accident in the past 5 years. Drivers with score of 11 or higher on the Epworth Sleepiness scale had a 3,8 fold higher odds of having had a near miss accident and a 2 fold higher odds of having been involved in an accident in the past five years.

Fatigue-inducing driving behaviour of professional truck drivers may be reinforced by specific driver compensation arrangements. In an interview study on 346 Australian long-haul heavy-vehicle drivers, Thompson and Stevenson (2014) found that drivers who were financially compensated per kilometer driven or per trip completed, reported significantly longer duration of driving without taking a break, significantly longer distances per day, significantly longer hours driven per day, and significantly longer working hours per week. Surprisingly these differences did not go together with similar differences on reported drowsiness while driving. Three explanations can be given:

- the drivers who were rewarded per kilometer or per trip possibly used illicit and/or legal stimulants to counteract the fatiguing effect of longer driving/working hours;
- the drivers who are less vulnerable to sleepiness volunteered for jobs with longer hours and distances
- the drivers inaccurately assessed or purposefully misrepresented their levels of drowsiness when interviewed (Thompson & Stevenson, 2014).

A 2012-2013 survey among 497 Italian truck and bus drivers indicated that over 40% of the professional drivers recalled falling nearly asleep at the wheel at least once a month (Rosso et al., 2014). The predictors for falling asleep were: advanced age (> 55 years), long distance trucking (traveling more than 40 thousand miles per year), obesity and self-reported fatigue (as measured by the Chalder Fatigue Questionnaire).

5.4 Shift workers

The term shift work describes regular employment outside normal daytime hours. Thus shift workers are likely to experience conflicting demands from work and their internal body clocks. Most shift workers have occasional sleep disturbances and approximately one-third complain of fatigue (Åkerstedt, 1995a, 1995b, 1995c). In a 2011-survey among more than 700 Portuguese drivers it was found that night shifts were associated with a 2,3 times higher odds of sleepy driving (Catarino et al., 2014).

A Finnish study looked at the combined effects of different forms of shift work, age, leisure-time physical activity, smoking and alcohol consumption on the prevalence of sleep complaints

and daytime sleepiness. 3.020 participants were studied using a psycho-social questionnaire. The participants were employed men, aged 45-60 years, from a postal and telecommunication agency, the railway company and 5 industrial companies. The researchers grouped the sleep complaints into the categories of insomnia, sleep deprivation, daytime sleepiness, and snoring. The prevalence of insomnia, sleep deprivation, and daytime sleepiness depended significantly on the shift system. All sleep complaints were more common in 2 and 3 shift working and in irregular shift working than in normal day working. The prevalence of daytime sleepiness was 20-37% depending on the shift system. Leisure-time physical activity and alcohol consumption were the most important life-style-factors in predicting all sleep complaints except snoring. The effects of physical activity and alcohol consumption differed for different shift schedules. The researchers concluded that working different shift patterns, 2-shift working and permanent night work increase the frequency of sleep complaints. 3-shift working seems to interact with life-style factors by increasing adverse effects and decreasing beneficial effects on sleep and sleepiness.

5.5 Conclusions

- US research shows that over one-third of its adult population has impaired functioning due to sleep loss during one or more days each month
- Surveys suggest that over half of all drivers drive while feeling drowsy at least once a year. A sizeable proportion of drivers had actually fallen asleep briefly at the wheel within the year prior to being interviewed (range 10% up to 40%).
- Amongst young drivers driving while drowsy is quite common due to lifestyle factors. Adolescents need more sleep than adults and fatigue may affect young people more than adults.
- Most professional drivers and shift workers have to cope with fatigued driving on a frequent basis due to work-related factors. According to surveys, half of all professional drivers sleep less than normal before a long-distance trip
- Even the more acute stages of fatigue, e.g. falling asleep briefly at the wheel, happen at least once a year for a considerable proportion of professional drivers.

6 Fatigue and road crashes

The study of fatigue and road crashes requires a definition of the characteristics of fatigue-related crashes. Definitions can then be applied to existing databases and estimates of the frequency of fatigue-related crashes obtained. Research that informs about the frequency of fatigue-related crashes is not conclusive scientific proof that fatigue directly leads to risk. The ultimate aim is to quantify the exact relationship between the level of fatigue and crash risk. To do this, research needs to control for other factors that may influence the relationship between fatigue and risk such as kilometres driven.

6.1 How to recognize a fatigue-related crash?

Unlike the situation with alcohol-related crashes, no blood, breath, or other measurable test is currently available to quantify levels of sleepiness at a crash site. Thus, current understanding of typical crash-related characteristics come largely from inferential evidence.

In the United Kingdom, fatigue-related crashes have been identified using the following criteria:

- The vehicle has run off the road and/or collided with another vehicle or object
- There is an absence of skid marks or braking
- The driver could see the point of run-off or the object hit prior to the crash
- Other causes are eliminated e.g. mechanical defect, speeding, excess alcohol, bad weather; and
- Witnesses may report lane drifting prior to the crash (Horne & Reyner, 1995, 1999)

Similarly, in the United States, the Expert Panel on Driver Fatigue and Sleepiness (NCSCR/NHTSA, 2001) characterises a fatigue-related crash as follows:

- The problem occurs during late night/ early morning or mid-afternoon
- The crash is likely to be serious
- A single vehicle leaves the roadway
- The crash occurs on a high-speed road
- The driver does not attempt to avoid a crash
- The driver is alone in the vehicle

6.2 Frequency of fatigue-related crashes

Different methods yield different estimates concerning the frequency of fatigue-related crashes. The following sections present estimates based on various methods:

6.2.1 Police records

The police crash reports in different countries, e.g. Netherlands, UK, North Carolina USA, indicate a 1-4% incidence of sleep-related crashes of all registered crashes (Schagen, van 2003). For Sweden and Switzerland, a similar range, 1-3% incidence of sleep-related crashes, is reported (Radun&Radun, 2009). For example, in the Netherlands, the combined primary cause of a crash that is attributed to sleep/illness occurs in about 1% of all registered crashes. It is likely that these police reports greatly underestimate the problem. In most countries, police are not (yet) so alert to fatigue as crash cause. Also, most drivers will be reluctant to admit that they were very tired or had fallen asleep at the time of the crash. In addition, the crash itself would have made most of the symptoms of fatigue disappear. So the 1% figure certainly represents an underestimation.

6.2.2 Questionnaire studies

Questionnaire studies have provided completely different conclusions about fatigue's role in road crashes (Schagen, van, 2003). Based on these methods, estimates of the percentage of sleep-related crashes vary greatly, but often are in the range of 10-25 percentage points higher than can be concluded from police reports. The higher percentages have been found particularly in studies that have examined lorry crashes and/or fatal crashes.

Based on findings from a survey study amongst 4.600 male car drivers in England, Maycock (1995) concluded that fatigue played a role in 9-10% of all crashes. This percentage was higher for motorways (20%) than for roads inside urban areas (7%) or for other roads outside urban areas (14%).

Goldenbeld et al. (2011) undertook a web-based panel survey among 2066 Dutch car drivers. The survey consisted of 67 questions which were arranged in themes about sleep (including

Epworth Sleepiness Scale), health, work, fatigue in everyday life, amount of driving, fatigue while driving, crashes and near-misses, countermeasures (use and effectiveness) and background. About half of the respondents (55%) reported that they had driven while being a little tired in the last 12 months. A quarter of the respondents (25%) reported that they had been so tired that they had had trouble staying awake at least once in the past year. One out of 10 respondents (10%) indicated that they had fallen asleep or almost fallen asleep behind the wheel at least once in the past year. It was found that individual vulnerability to daily sleepiness as measured by the Epworth scale was the strongest predictor of dozing off behind the wheel. For drivers that reported a small chance of dozing off in everyday (non-driving) situations, the odds of dozing off behind the wheel were a factor 4.5 larger compared to drivers that reported that there was no chance at all they would fall asleep in an everyday situation.

6.2.3 Naturalistic observation study

Naturalistic observation of driving behaviour provides the most direct evidence of driver fatigue in real circumstances. A naturalistic driving study unobtrusively registers the actual driving behaviour of drivers who drive their own cars to destinations of their own choosing without an experimenter present. The registration of driving behaviour is continuously done by various instruments over a longer period of time (one year or longer). A naturalistic observation study may link the outward signs of fatigue (such as closed eyes) to real driving behaviour.

The 100-Car Naturalistic Driving Study is an instrumented vehicle study designed to collect a large volume of naturalistic driving data over an extended period of time. The researchers installed instruments and sensors in 100 vehicles that were then driven as ordinary vehicles by ordinary drivers for one year. Drivers were given no special instructions, no experimenter was present and the data collection system was unobtrusive. In addition, drivers' own vehicles were instrumented for 78 out of 100 vehicles.

The study collected data on 15 police-reported and 67 non-police reported crashes, 761 near-crashes (situations requiring a rapid, severe evasive manoeuvre to avoid a crash) and 8.295 incidents (situations requiring an evasive manoeuvre occurring at less magnitude than a near-crash). In this study, fatigue was judged to be a contributing factor in approximately 12% of crashes, 10% of near-crashes, and 7% of crash-relevant conflicts (Dingus et al., 2006). Fatigue was measured by an observer rating of drowsiness, measured on a scale from 0 to 100 in increasing severity of drowsiness. The scale was based on the Wierwille and Ellsworth (1994) rating system for driver fatigue. This rating system is based on observable personal characteristics such as facial tone, eye blinks, eye closures, head movements, staring, lack of activity, eye expression etc.

In another analysis of the 100-Car Naturalistic Driving Study, it was estimated that the odds of being involved in a crash or near crash were nearly three times higher when the driver was drowsy, compared to not being drowsy (OR = 2,9). The estimated population attributed risk, or PAR, for driving while drowsy, taking into account the prevalence of the behavior in the driving population, was 22–24% of all crash and near crash events (Klauer et al., 2006a, 2006b).

Box 4. Naturalistic study local / short haul truck operators

Barr et al. (2011) performed a naturalistic field study of driver drowsiness among local/short-haul (L/SH) truck operators. L/SH operations primarily involve trips of 100 miles or less from the home base. L/SH drivers usually start and end their workdays at their home base. A total of 42 drivers from two L/SH trucking companies participated in the field study, in which in-service L/SH trucks were instrumented with data collection equipment. Each driver drove an instrumented truck for approximately 2 weeks. The instrumentation consisted of sensors to monitor vehicle parameters (i.e., velocity, lateral and longitudinal acceleration, steering position, and brake pedal activation). Each truck was also equipped with video cameras that provided exterior views of the driving environment and interior images of the driver's face. A total of 2,745 drowsy events were identified in approximately 900 total hours of driving. Thus, the rate of drowsy occurrences for all drivers combined was 3,1 events per hour of driving.

One of the major findings of this study was consistent evidence for a strong association between drowsiness and time of day. The early-morning time period between 6am and 9am was especially problematic for the L/SH drivers. Drowsiness was twice as likely to occur between 6am and 9 am, and a linear regression model indicated a significant relationship between this time period and an increase in the proportion of time over the 3-minute event interval that the driver's eyes were closed or nearly closed, the primary measure of drowsiness used in this study. Conversely, a decrease in eye closure (i.e., increased alertness) was associated with the time period between 12pm and 3pm. These results, together with the finding that approximately 30% of all observed instances of drowsiness occurred within the first hour of the work shift, suggest that drivers may not be fully refreshed and awake when they begin their workday.

Drowsiness was also found to be associated with younger and less experienced drivers. Odds-ratios indicated that drivers in the 19–25-year-old age group were 9 times more likely to be classified in the “High Fatigue” group than older drivers. Similarly, inexperienced drivers with less than 1 year of commercial driving experience were about 7 times more likely to be “High Fatigue” drivers than were those with more driving experience.

The study provided quantitative evidence on the hypothesis that drivers suffering from fatigue and/or drowsiness experience “tunnel vision.” When a driver becomes drowsy, the rate of eye transitions and the proportion of time his/her eyes are off the forward roadway were both found to decrease. Therefore, a drowsy driver is less aware of the driving environment around him/her and his/her ability to recognize potential hazards from other vehicles or objects outside the vehicle is compromised.

Observation of driver behavior from the continuous video data revealed that in the majority of cases, drowsiness occurred during periods of extremely low driver workload brought on by boredom and monotony. In these cases, the driver would often respond by engaging in secondary activities typically associated with driver distraction or drowsiness countermeasure activities, in an effort to increase his workload.

6.2.4 In depth crash investigation

In-depth studies investigate characteristics of crashes to find out whether fatigue may have played a role. In an in-depth study, Horne and Reyner (1995) established that about 20% of crashes on motorways were sleep-related. The injury level of these crashes is quite high since no braking occurs.

In France, Philip et al. (2001) applied the criteria from Horne and Reyner on serious injury crashes in the period 1994-1998. This study looked at single vehicle crashes under good weather and road conditions on road segments without intersections. They found that about 10% of 68,000 analysed crashes were related to fatigue (as determined by the Horne/Reyner criteria). This is probably an underestimation since collisions with other vehicles that satisfied the Horne/Reyner criteria were not taken into account.

In Germany, a similar in-depth crash study established that about 24% crashes on a German motorway had to do with fatigue (Langwieder&Spornier, 1994).

In Finland, all fatal road crashes are investigated in-depth by multidisciplinary investigation teams. The percentage of fatal crashes involving fatigue or falling asleep between 1995 and 1999 fluctuated between 16-19% (Hantula, 2000 in: ETSC (2001).

Haworth et al. (1989) estimated sleep or fatigue to be involved in about 20% of truck- involved fatal crashes. Based on a literature study involving both in-depth and questionnaire studies, Amundsen and Sagberg (2003) found that fatigue was a contributing factor in 15 to 20% of truck crashes.

The Large Truck Crash Causation Study involved a collection of over 1.000 variables on 1123 large trucks involved in 963 serious injury crashes occurring in 17 U.S. States (Craft, 2007). Drowsiness was cited as a causative factor in 13% of the crashes and was associated with an 8-fold increase in crash risk.

Based on crash research, Sagberg et al. (2004) provide the following estimates of proportion of crashes that are sleep or fatigue related.

Table 2. Proportion of crashes related to sleep or fatigue

Crash category	%	Number of studies
All	1-6%	7
All fatal	3-15%	3
Truck driver crashes	2-41%	5
Truck drivers fatal crashes	4-31%	3

Source: Sagberg et al., 2004

Since under-reporting concerning sleep or fatigue involvement in a crash is more likely than over-reporting, the true proportions are probably closer to the upper than to the lower limits of the intervals.

6.3 Fatigue and crash risk

The finding that fatigue is involved in 10-25% crashes does not in itself prove that fatigue increases crash risk. For example, it could be that drivers who are more fatigued also drive more kilometres than other drivers, so that the risk per kilometre is the same for fatigued and non-fatigued drivers. Several studies have investigated the relationship between driver fatigue and crash risk and have attempted to quantify the increased risk. Often increased risk of particular groups such as young drivers or professional drivers derives from a combination of factors.

6.3.1 How dangerous is fatigued driving?

Several studies have investigated the relationship between driver fatigue and crash risk and have attempted to quantify the risk increase. Reviewing these studies, Connor et al. (2001) concluded that nearly all studies were limited in their ability to establish a causal relationship. Study limitations concerned design, biases and in many cases, small sample sizes. Despite these limitations the better quality cross-sectional studies do suggest a positive relationship between fatigue and crash risk. A reliable estimate of the strength of the association cannot yet be given.

In a case control study of New Zealand drivers, Connor et al. (2001) compared 571 crash-involved drivers with 588 non-crash involved drivers driving in the same area and at the same times. Driver variables were taken from crash registration and additional interviews. Taking into account possible confounding variables (gender, age, socio-economic status, annual kilometres, speed, road type), they found a strong relationship between acute fatigue (based on loss of sleep the night before) and crash involvement. Crash risk was 8 times higher for drivers with a score ≥ 4 on the Stanford Sleepiness Scale (95% confidence interval 3,4-19,7); 5,5 times higher for driving between 2 and 5 am (95% interval 1,4-22,7); and almost 3 times higher when drivers had slept for less than 5 hours in the past 24-hour period (95% confidence interval 1,4-5,4).

In a case-control study, Cummings et al. (2002) compared crash-involved drivers with a similar group of non-crash involved drivers at the same location, direction, time and day. They found the crash risk was 14 times higher for drivers who had reported almost falling asleep behind the wheel (95% confidence interval 1,4-147).

The data collected in The 100 Car Naturalistic Driving Study shows that driving while fatigued increases a driver's risk of involvement in a crash or near-crash by nearly 4 times (Klauer et al., 2005).

Studies of professional drivers (bus, lorry, truck) show that it takes around 9 or 10 hours of driving, or 11 hours of work, before crash risk starts to rise (Mackie & Miller, 1978). Hamelin found that after 11 hours of work span the crash risk doubles. The effect of task duration is practically always entangled with the effects of the time of day and sometimes also with the length of time awake and previous lack of sleep. The duration of a trip may be of lesser importance compared to these other factors – many fatigue-related crashes occur after driving for only a few hours (Sagberg, 1999; Stutts et al., 2003). Short trips can also end up in fatigue-related crashes because time of day and long and irregular working hours are stronger predictors of fatigue than time spent driving (Brown, 1994; Wylie et al., 1996).

Connor et al (2001) also note blind spots in the research on driver fatigue. The association of non-medical (lifestyle) determinants of fatigue with crash has not been the subject of thorough research. There is still a lack of knowledge concerning the contribution of increasing total hours of work and shift schedules to driver fatigue. Whereas research into fatigue and sleep apnea in truck drivers has led to awareness of these problems and some modification of work conditions (Feyer et al, 1997; McCartt et al., 1997; Mitler et al., 1997), occupationally induced fatigue in potentially much larger numbers of commuters has received little attention.

Herman et al. (2014 a, b) undertook a population-based case control study which included 131 motor vehicles involved in crashes where at least one person died or was hospitalised (cases) and 752 motor vehicles identified in roadside surveys (controls). An interviewer-administered questionnaire completed by drivers or proxies collected information on potential risks for crashes (including sleepiness while driving and sleep-related factors). The researchers used a four-level sleepiness scale which drew conceptually from the Stanford Sleepiness Scale, a validated self-rating tool for measuring acute sleepiness. The researchers concluded the following on driver sleepiness and traffic risk: Drivers who were not fully alert or sleepy (in comparison to drivers who were fully alert) were six times more likely to be involved in injury-related crashes. Drivers who reported less than six hours of sleep (in comparison to more than six hours) in the previous 24 hours were six times more likely to be involved in injury-related crashes. Based on this study

the researcher estimated that the incidence of four-wheel motor vehicle crash injuries in Fiji could fall by 34% if there were no drivers driving while sleepy or not fully alert, and by 9% if there were no drivers driving after less than six hours of sleep in the previous 24 hours (Herman et al., 2014 a, b).

6.3.2 Combination of factors

Frequently a combination of situational and individual factors contributes to increased risk of being involved in a fatigue-related crash. The increased risk may be attributed to a mix of biological, lifestyle, and work-related factors. For teenage drivers, the strong biological need for sleep and going out in weekend-nights may combine to increase fatigue and risk (Groeger, 2006). For professional drivers and long distance drivers, both reduced sleep and long working hours combine to increase fatigue and risk (Jetting et al., 2003; Miller & Mackie, 1980; Philip et al., 2005).

Stutts et al. (2003) investigated both situational factors and individual differences in fatigue-related traffic risk. The database consisted of police crash reports and surveys from 312 drivers who fell asleep at the wheel, and surveys from 155 drivers who had caused a crash as a result of fatigue. The study used as a control group 529 drivers, who were responsible for a crash which was not caused by fatigue and 407 collision-free drivers.

The researchers found that drivers responsible for a fatigue-related crash more often had several jobs, were shift workers or had unusual working hours. In addition, these drivers reported to sleep less hours at the average, to feel more tired during the day, to drive more often at night-time and to have experienced drowsiness at the wheel more frequently. In comparison to drivers with crashes without fatigue origin, these drivers drove on average longer, were awake more time, slept less at night and used barbiturates more often. 23% of the drivers with fatigue-related crashes reported to have driven in the past year 10 or more times in a fatigued state. 19% of these drivers reported to have been awake more than 20 hours before the crash. The authors conclude, that the crash risk due to fatigue is significantly increasing, if the driver sleeps less than 7 hours. Compared to driver averaging 8 hours of sleep or more, drivers who sleep less than 5 hours per night on average are 6 times as likely to be involved in a fatigue related crash (versus not being in a crash at all).

6.4 Conclusions

- Fatigue-related crashes are often associated with high injury levels
- Fatigue is a major factor in a large proportion of road crashes (range 10-20%)
- Several studies suggest that fatigue is associated with increased crash risk. Estimates range between a 3 to 8 times crash risk increase due to insufficient sleep in the night before the trip.
- The increased risk often results from a combination of biological, lifestyle- and work- related factors
- More scientific evidence is needed concerning the exact quantitative relationship between fatigue and risk.

7 Risk groups

Specific groups of drivers engage more frequently in fatigued driving and thus have a higher risk of being involved in a fatigue-related crash. According to reviews, groups of drivers that have a higher risk of being involved in a fatigue-related crash are young drivers (< 25 years); professional drivers; long-distance drivers; shift workers; drivers with sleeping disorders.

7.1 Young drivers

Sleep complaints are common during adolescence (ranging from 9,5% - 46% of young people) and may represent clear-cut sleep disorders such as sleep disordered breathing, restless legs syndrome, narcolepsy, insomnia, or circadian rhythm sleep disorders or they may reflect lifestyle factors affecting sleep quality (Pizza et al., 2010).

Based on a literature review, Lyznicki et al. (1998) concluded that younger drivers are a high-risk group for fatigue-related crashes. Young adults are involved in two-thirds of all sleepiness-related crashes, especially those occurring late at night or early in the morning (Garbarino et al., 2001). Late-night driving, together with chronic sleep debt, the poor experience of how to cope with fatigue and the insufficient driving ability may partially explain the high risk of sleep-related crashes amongst young adults (Lyznicki et al., 1998; Pizza et al., 2010). Within the young driver group as a whole, teenagers may be even more susceptible to effects of sleep loss than young adults. According to sleep-research, adolescents require 9 to 10 hours of sleep per night, but youths sleep significantly less, and adolescents cannot compensate for the chronic sleep deprivation accumulated during weekdays during the weekend (Pizza et al., 2010).

Several studies have found that young drivers, and males in particular, were the most likely to be involved in falling-asleep at the wheel crashes (Pack et al., 2005; Horne & Reyner et al., 1995; Maycock, 1996; Åkerstedt & Kecklund, 2001). For example, Åkerstedt and Kecklund (2001) studied the factors associated with involvement in early morning crashes (from midnight to 6 am), controlling for driving exposure. They reported that the highest risk for early morning crashes was for younger drivers. Their crash risk at this time was at least 5 times higher than their risk when driving at other times. The high risk for younger drivers was greatest for young males.

In a study of young Italian drivers (mean age 18.4), Pizza et al. (2010) studied sleep-related and other risk factors. Compared with adolescents who had not had a crash, those who had at least 1 previous crash reported that they more frequently used to driving at night (79% vs. 62%), drove at night (25% vs. 9%), drove while sleepy (56% vs. 35%), had bad sleep (29% vs. 16%) and used stimulants such as caffeinated soft drinks (32% vs. 19%), tobacco (54% vs. 27%) and drugs (21% vs. 7%). Analysis revealed a significant predictive role of male sex (OR = 3,3), tobacco use (OR = 3,2), sleepiness while driving (OR = 2,1) and bad sleep (OR = 1,9) for the crash risk.

The increased risk of adolescents having a sleep-related crash can be partially explained by the chronic sleep-deprivation hypothesis. A one-hour delay in high-school start times has been shown to significantly reduce the risk of motor vehicle crashes through meaningful increases in night-time sleep (Danner & Philips, 2008).

Filtiness et al. (2012) tested the hypothesis that young drivers are more vulnerable to the effects of sleep loss compared to older men. They assessed the effect of normal night sleep versus prior sleep restricted to 5h, in a counterbalanced design. Under the different conditions of the experiment, young (average 23 years) and old drivers (average 67 years) engaged on prolonged afternoon driving. All respondents were healthy men who drove a full size, real car simulator under monotonous 'motorway' conditions for 2h during the 'afternoon dip'. Driving was monitored for sleepiness related lane deviations, EEGs were recorded continuously and subjective ratings of sleepiness were taken every 200sec throughout the drive. Following normal sleep there were no differences between groups for any measure. After sleep restriction, and compared with the older group, the younger drivers showed significantly more sleepiness-related deviations, greater 4-11Hz EEG power and a near significant increase of subjective sleepiness. This study confirms the greater vulnerability of younger drivers to sleep loss under prolonged driving, even during the early afternoon.

The age factor may also play a role with professional drivers. In a simulator study, Otmani et al. (2005) found that young professional bus and coach drivers had more difficulty to drive in a low traffic condition and felt sleepier during low traffic driving in the late evening than middle-aged professional drivers.

7.2 Professional truck drivers

Fatigue is a particular problem for professional drivers, and especially truck drivers. In practice, the particular job demands of long-haul transport industry often interfere with normal rest. World-wide transport industry work practices include working long hours, prolonged night work, working irregular hours, little or poor sleep, and early starting times. Many truck drivers work more than 12 hours per day, of which at least 60% is usually spent driving (Buxton and Hartley, 2001). A working week of over 70 hours is common practice for many owner drivers. These long hours of work may result in drivers obtaining less than the necessary 7 to 8 hours of sleep and cause fatigue (Buxton and Hartley, 2001). In the USA about 20% of all crashes and fatalities involving a long-haul truck, occur between midnight and 6am, the peak period of driver fatigue (Blower et al., cited in: ROSPA (2001)).

French research into lorry driver working times and habits showed that risk levels vary with three key factors as regards the general problem of fatigue (Hamelin, 1987; Hamelin, 1992; Hamelin, 1999; Charbotel et al., 2001). There is an increased risk of crashes at night, an increased risk the greater the length of the working day, and also with irregular working hours.

Research points to increased crash risk with a greater number of hours driven. However, studies show different results concerning the length of driving time needed before risk increases. Mackie and Miller (1978) found some aspects of driving performance deteriorated after 8 to 9 hours driving. They analysed 750 truck crashes which clearly involved driver fatigue or were single-vehicle crashes (which made it very likely they were driver fatigue-related). They found twice the probability of a crash in the second half of a trip, as compared to the first half of the trip, and the odds of a crash started to rise after 5 hours driving. Folkard (1997) undertook a meta-analysis of several studies of hours of driving and crash risk. Folkard found that there was a rise in likelihood of a crash at two hours into the trip before risk dropped back to starting levels at 4 hours into the trip. The likelihood of a crash then started to rise again the more hours driven

until at 11 hours the risk was higher than at any previous time. The US Federal Motor Carrier Safety Administration (FMCA, 2000) has published data showing the relative risk of a fatigue crash and hours driven. As in Folkard's 1997 data and Hamelin (1987), crash risk starts to rise after 10 to 11 hours of driving. The US data shows that the risk of a crash rises seven fold after this period of driving. In summary, the results of various studies are not quite consistent and should be interpreted with some caution. In these studies, the effects attributed to hours of driving may also have been influenced by a down turn in the circadian rhythms or by prolonged wakefulness (Buxton & Hartley, 2001).

The US National Transportation Safety Board (1995) examined 107 single heavy goods vehicle crashes where the drivers survived and records of their activities over the previous 4 days were available. 58% of those crashes were judged to be due to fatigue; and in 18% of those crashes the driver was asleep at the wheel. In the fatigue crashes the Safety Board found that more drivers had: an inverted sleep/waking cycle; driven at night with a sleep debt (chronic sleep shortage); had slept only 5.5 hours in the past 24 hours compared to 8.8 hours in other crashes not due to driver fatigue; and had fragmented sleep between night and day.

A Dutch survey study amongst 537 truck drivers investigated determinants of both chronic and acute fatigue (defined as actually dozing off or falling asleep behind the wheel) (Jettinghoff et al., 2003). Surprisingly, drivers who worked for 60-65 hours per week did not feel more tired than drivers who worked for shorter time (52-56 hours). Factors that were linked to chronic fatigue were, in decreasing order of importance: few possibilities to learn new skills, competence or apply creativity; not taking the time to eat well; sleeping problems; relative ill health; being a parent; use of medicine; large pressure of working times on family life; smoking; large pressure of family life on work; lack of vegetable intake. Indirectly, long working hours play a role in the causation of chronic fatigue. The two factors indicating interference between professional and private life are the most important factors in explaining chronic fatigue.

In that same study, the factors that were most strongly linked with acute fatigue were in decreasing order of importance: lesser general health; amount of alcohol intake; good (comfortable) cabin climate; more frequent violations of official work and driving times regulations; being busy with other things besides driving (e.g. using mobile phone); driving singly instead of in a team; more often having work progress meetings; not having a fixed contract.

7.3 Taxi drivers

Besides truck drivers, taxi and bus drivers should be mentioned as professional driver groups who are at increased risk of becoming involved in a fatigue-related crash. Research in New South Wales indicates that taxi drivers are more than twice as likely to be killed or seriously injured while driving at work or while commuting (Fletcher & Mitchell, 2011). Taxi drivers are prone to fatigue-related risks, made worse by the very nature of the work which often requires long hours and driving at all times of the 24-hour day. Factors associated with an increased crash risk in taxi drivers include longer shifts and shorter total break times during shifts (Fletcher & Mitchell, 2011). Taxi drivers exhibit an optimistic bias concerning their ability to drive fatigued and generally seem to display a low level of awareness of fatigue risks. There are likely to be drivers at even greater increased risk of fatigue due to undiagnosed or untreated sleep disorders. In a study on driver fatigue in professional drivers in Chinese Beijing, Meng et al. (2015) confirmed

that driving fatigue is a serious safety problem for taxi drivers, as serious or even more serious than among truck drivers, and that long shifts are a contributing factor to the problem. Also, replicating findings from Fletcher & Micthel, Meng et al (2015) conclude that taxi drivers are overly optimistic regarding their fatigue and overconfident in their ability to counteract the effects of fatigue.

7.4 Shift workers

Work schedules vary by a number of criteria, including the timing of work hours, shift length, shift schedule (fixed or rotating), speed of shift rotation and number of days off. These combined factors together with type of work performed, job control, sleep requirements, personal characteristics and domestic situation determine level of fatigue and fatigue-related outcomes (Di Milia et al., 2011).

The shift worker cannot sleep when sleep is desired, needed, or expected by his own body, and thus, is likely to suffer from chronic sleep loss (Axelsson, 2005). Not surprisingly, being engaged in shift work is associated with increased traffic risks. For example, a study by Folkard (1999) showed that the risk of being in a single-vehicle crash at 3 o'clock in the morning was 50% above the baseline after four successive night shifts.

Fatigue-related crashes tend to occur in two distinct periods of the day – between midnight and 6am, and between about 2pm and 4pm (Maycock, 1997; ROSPA, 2001). These periods coincide with typical low-points in our daily pattern of alertness, or circadian rhythm. Drivers who work irregular schedules are most likely to be affected by the body's natural desire to sleep during the night. Studies on driver fatigue have typically used vehicle control and psychophysiological measures as indices of driver drowsiness. These studies have found that time of day has a larger impact on driver fatigue than time on task (Brown, 1994; Mitler et al., 1997)

Shift workers form a large part of the working population. Approximately 24% of the European population work on a regular 8-hour schedule during daylight hours (07.00-18.00) and 5 days per week. 17% are engaged in shift work and 14% have long shifts (at least 10h) on a regular basis (Axelsson, 2005).

7.5 Drivers with medical conditions

Daytime fatigue can be caused by sleep-related or general medical conditions.

Those with obstructive sleep apnea syndrome (OSAS) frequently complain of excessive daytime fatigue and sleepiness because of non-restorative and continuously disrupted sleep. OSAS is probably the most studied medical condition with respect to traffic crashes. The prevalence of OSAS in the general population is between 2% and 4%, although it is estimated to be between 26% and 50%, among professional drivers (Smolensky et al., 2011).

Ellen et al. (2006) performed a meta-analysis of 40 OSAS studies pertaining to driving crash risk of both non-commercial and commercial drivers. For non-commercial drivers, 23 of the 27 studies, including 18 of the 19 that involved a control group, showed a statistically significant increased driving risk for OSAS, with many of the studies documenting it to be two- to three-

times higher than the control group. However, risk was not consistently related to OSAS severity. For commercial drivers, the relationship between OSAS and traffic crashes was not robust, in that only one of the three considered studies found an increased crash rate, and, furthermore, in these three studies the association between OSAS and crashes was weak (OR = 1,3). Overall, a correlation between one's self-recognized fatigue/sleepiness and driving incidents was found in only half of all the reviewed studies. Nonetheless, taken together Ellen et al. (2006) meta-analysis confirms the expected association in non-commercial drivers between OSAS and crash risk. Yet, this relationship was not confirmed for commercial drivers. According to Smolensky et al. (2011), differences among the driver samples, for example, sleep-span duration/sleep deprivation, or medication use may have acted to modify or obscure the risk of OSAS in commercial drivers.

Narcolepsy is a disabling neurologic condition affecting 1 in 2000 individuals (Mignot, 2004 mentioned in Smolensky et al., 2011). It is characterized by excessive, oftentimes extreme, daytime sleepiness, cataplexy (attacks involving loss of muscle tone and weakness), and frequent transitions during the daytime between wakefulness and rapid-eye-movement (REM) sleep. The prevalence of narcolepsy combined with cataplexy is estimated to be between 25 and 50/100.000 (based on research mentioned in Smolensky et al., 2011). At present, there are too few sufficiently large studies, especially prospective population-based ones, to determine with confidence the actual magnitude of risk posed by narcolepsy for sleep-related crashes (Smolensky, 2011).

Many medical conditions not classified as sleep disorders may also be a significant source of excessive daytime fatigue, compromised cognitive functioning, and drowsy driving, among which, for example, asthma, alcoholism, Parkinson's disease, allergic rhinitis, nocturnal asthma, rheumatoid arthritis/osteoarthritis, chronic obstructive pulmonary disease (COPD), chronic fatigue syndrome (Smolensky et al., 2011). Many prevalent medical conditions can cause or contribute to elevated or excessive daytime fatigue and drowsy driving. The contribution of excessive fatigue by these and other widespread medical conditions to drowsy-driving traffic incidents seems to be largely unappreciated and not yet adequately addressed.

Only a small number of case control, population-based, epidemiology studies have focused on the potential involvement of medical conditions and/or prescription and over-the-counter (non-prescription) medications in road crashes. These investigations have entailed cohorts of surviving at-fault drivers ≥ 65 years of age, an age group that tends to be over-represented in traffic crashes. The findings reveal an increased odds ratio for those with existing heart disease, hypertension, previous stroke, or arthritis in women, but not diabetes (Smolensky et al., 2011).

There has been no study that addresses the potential confounding or interactive effects of medical condition, medication and dose level, and/or other demographic variables (e.g., Di Milia et al., 2011; Smolensky et al. 2011) recommend that investigations into effect of medical condition or treatment be extended to examine the impact of extensive driving or extended work shifts in treated and non-treated individuals.

7.6 Conclusions

- Compared to the average driver, professional drivers, long distance drivers, shift workers, young drivers, taxi drivers and drivers with a sleeping disorder have an increased risk of being involved in a fatigue-related crash
- Compared to average drivers, drivers with obstructive sleep apnea syndrome may be 6 times more likely to be involved in a fatigue-related crash
- The increased risk often results from a combination of biological, lifestyle- and work- related factors.
- Within the general group of young drivers, teenagers are more susceptible to effects of sleep loss than young adults. For teenagers, a one-hour delay in high-school start times can significantly reduce the risk of sleep-related crashes.

8 Countermeasures

Driver fatigue countermeasures may be directed at drivers, transport companies, roads, or vehicles. Drivers may increase their awareness of how to prevent driver fatigue through campaigns. Transport companies can introduce special policies to educate both drivers and management about the problem. Roads may be equipped with edge lines or centre-lines that provide audio-tactile feedback when crossed over. In the future, legislation concerning working and rest hours may be further improved and vehicles may be equipped with devices that detect fatigue-related decrements in driver performance.

8.1 Publicity campaigns

Publicity campaigns may raise awareness about the problem of driver fatigue and possible countermeasures. Possible campaign themes may include (Fletcher et al., 2005):

- Driving when fatigued is a risk equal to driving drunk
- Tactical use of driver rotation, caffeine, napping
- Encouraging drivers to consider fatigue-related driving risk as a personal responsibility
- Educating the community on minimum sleep requirements and fatigue warning signs
- Challenging existing incorrect beliefs about personal ability to cope with fatigue
- Targeting specific populations (such as driving schools, sleep disorder clinics) with direct education.

Williamson et al. (2014) suggest that increasing the legal penalties for crashes that are identified as fatigue-related may support the salience of the message of fatigue campaigns. Such a combination of education and enforcement would be needed to better target safe decision-making around driving while fatigued or sleepy.

Fatigue awareness campaigns have been used in USA, Australia, New Zealand, UK, France and Germany. 'Don't drive tired' messages feature on variable message signs in Europe and some US states. The UK Department for Transport has featured tiredness in its Think! Road Safety campaign since 2000. Qualitative research led to recommendations for improvement of the campaign: See

<http://www.thinkroadsafety.gov.uk/campaigns/drivertiredness/drivertiredness.htm>

However, evaluations of campaign effects on behaviour and crashes are generally lacking. A road safety publicity campaign, by itself, has only modest impact on attitudes and behaviour and no significant impact on crashes. Campaigns work best when combined with other interventions, such as enforcement of traffic laws and regulations, or provision of other safety services and products (Delhomme et al., 1999).

Based on literature review, Fletcher et al. (2005) provide the following recommendations to improve driver fatigue campaigns:

- More formal identification of fatigue as a risk, for example being tired is like being drunk.
- Emotional stimulation of the consequences of fatigue, for example, if you fall asleep and kill someone, you are personally responsible, and therefore criminally liable.
- Techniques to promote self-awareness of fatigue and also to identify fatigue in others, for example if you cross a rumble strip more than twice within 10 minutes then you need to take a break.
- Practical approaches to assist drivers and passengers to minimize driver fatigue by obtaining adequate sleep and maximizing the use of other preventive strategies, for example you will know when you are tired, but you will not know when you are going to fall asleep.
- Evaluation programs to collect and interpret data for the international road transport community on actual efficacy of specific strategies.

In the area of driver fatigue as in other health-related areas, awareness may not be enough to motivate drivers to adopt self-protective behaviour. Reyner and Horne (1998) note that perception of sleepiness does not result in cessation of driving. Nordbakke and Sagberg (2007) found that a large proportion of drivers did not get sufficient sleep before a long drive or did not stop and take a nap when they experienced sleepiness while driving. The drivers did not take these precautions despite their awareness of the risks involved in these behaviours. Although it is possible to educate or teach drivers to become more aware of the early signs of fatigue or sleepiness, it is probably very difficult to make them take a break from driving. Sagberg (1999) believes that a strong motivation to reach their destination in time will make drivers try various ways of combating fatigue. However, this is exactly the combat that the driver often loses. In this regard, a problem for public fatigue campaigns is that fatigued driving by private drivers is not punishable by law. It is therefore difficult if not impossible, at least where private drivers are concerned to link public campaign themes with enforcement or legal consequences. For professional drivers, the case is different since there is legislation and the possibility of enforcement concerning work and rest hours.

With respect to general campaign effectiveness, Haworth (2003) notes that different media have different roles. TV and print-media interventions are useful for education/altering beliefs and norms over a period of time, whereas radio and roadside billboards (and in-car stickers) are useful for reminding drivers of fatigue issues and prompting immediate counter-behaviours. Other programme elements that can enhance a driver fatigue campaign are:

- working in combination with community, interest group and individual activities
- coordination with other services to encourage initial behaviours (such as hotlines for initial information) and to support established behaviours (such as brochures in cafes, petrol stations, roadside cafes, information centres)
- coordination with websites to provide relevant support materials.

8.2 Road infrastructure measures

Infrastructural measures to reduce fatigue-related crashes include improved delineation treatments (e.g. rumble strips, profiled lane markings), safety fences on the central reservation or at the roadside. These measures are aimed at preventing drivers from driving off the road or hitting drivers coming in the opposite direction. In various countries, these measures have been effective in reducing the chance of driving off the road or hitting a vehicle or obstacle (ETSC, 1998).

Box 5. Rumble strips as fatigue countermeasure

Rumble strips are raised or grooved patterns on the roadway shoulder that provide both an audible warning (rumbling sound) and a physical vibration to alert drivers that they are leaving the driving lane. In addition to warning inattentive drivers, rumble strips help drivers stay on the road during inclement weather when visibility is poor.

The use of milled shoulder rumble strips (SRS) has been very effective in reducing single-vehicle run-off-the-road crashes caused by driver inattention, distraction, or drowsiness. Milled can be placed on either new or existing asphalt or cement concrete. A milled SRS is made with a machine that cuts a smooth groove in the roadway's shoulder. A SRS pattern results when SRS are repeated at regular intervals. This type of SRS modifies the pavement surface and provides for a vehicle's tires to drop, which creates high levels of vibrational and auditory stimuli. In Virginia, a 3 year (1997-2000) experiment with continuous shoulder rumble strips (CSRS) on the State's 1.476-kilometer interstate highway system showed that run-off-road crashes were reduced by 51,5%, saving estimated 52 lives. Similarly, the judicious use of centreline rumble strips on undivided roads reduces the number of head-on collisions.

http://safety.fhwa.dot.gov/roadway_dept/rumble/synthesis/pro_res_rumble_library.htm

Mackie and Baas (2007) refer to shoulder and centreline rumble strips as audio tactile profiled (ATP) edge and 'no overtaking' centrelines. Based on New Zealand data, Mackie & Baas (2007) report favourable benefit-cost ratios (BCR) for ATP-treatments on roads with relatively modest traffic counts and much higher BCRs from higher traffic counts.

8.3 Technological approaches

Dinges and Mallis (1998) described four technological approaches to monitoring or prediction of fatigue of drivers (or employees in general):

1. Readiness-to-perform and fitness-for-duty technologies that assess reaction time, psychomotor tracking, or vigilance and alertness capacity of an employee before the work is performed (i.e., prior to the start of the work shift), most often by the use of performance-based tests (e.g., measuring reaction time) or tests that measure ocular physiology.
2. Mathematical models/algorithm technologies that predict employee alertness and performance at different times, based on interactions of the amount of sleep obtained or missed, on circadian factors, on the present workload, and on related temporal antecedents of fatigue.
3. Vehicle-based performance technologies that measure vehicle performance parameters (e.g., steering movements, vehicle speed, or the movements of the vehicle within the lane markers on the roadway) and infer driver behavior by monitoring the continuity of steering wheel movements and/or vehicle speed or by examining the driver's ability to maintain adequate lane-tracking movements while steering the vehicle.

4. Vehicle-based operator alertness/drowsiness/vigilance monitoring technologies that monitor some biobehavioral aspect of the driver such as eye gaze, eye closure, pupil occlusion, head position and movement, brain wave activity, heart rate, etc. To be practical and useful as a driver assistance system, these devices must acquire, interpret, and feedback information in real-world driving environments.

Recent reviews concerning fatigue-detection technologies have concluded that further development of these devices is needed. After reviewing the literature on vehicle measures to detect driver drowsiness, Liu et al. concluded that a successful technological countermeasure will require the setting of multiple criteria and the use of multiple measures (Liu et al., 2009). In order to develop a successful technological warning device for driver drowsiness, a number of outstanding issues need to be addressed: (a) relating simulator and real-world driving behavior; (b) reducing raw vehicle data; (c) defining critical events; (d) specifying a critical time window; (e) setting an appropriate criterion; and (f) combining multiple measures. In a paper on technological countermeasures, Balkin et al. (2011) concluded that the most reliable estimates of driver fatigue will incorporate both physiological measures and non-intrusive, objective measures of performance (Balkin et al., 2011).

A system that uses multiple components (e.g., operator and performance monitoring) is likely to be more effective than one that focuses on one dimension alone. Each system has advantages and drawbacks. Until now, no single technological system has fulfilled all of the criteria specified by Dinges and Mallis (1998). An important consideration in the implementation of these systems, which has not been adequately addressed to date, is the acceptance and use of the system by road users (Horrey et al., 2011).

Recent technological developments in the field of fatigue detection include the use of computer vision to detect driver drowsiness (e.g. Chakraborty & Hossain, 2014; Massala & Grosso, 2014) and the use of non-intrusive biopotential measurement systems that require no contact with the human skin (e.g. Sun, & Xion, 2014).

8.4 Vehicle-based detection and warning devices

Several related concepts 'Driver Vigilance Monitoring', 'Drowsiness Detection Systems', 'Fatigue Monitoring Systems' refer to in-vehicle systems that monitor driver and/or vehicle behaviour. These systems monitor the performance of the driver, and provide alerts or stimulation if the driver seems to be impaired.

Driver and vehicle monitoring systems may monitor both driver and vehicle behaviour. Information can be gathered from driver input and control of the vehicles lateral position and speed, such as acceleration, steering wheel movement and lane position. Likewise, user behaviour such as eye movement, facial feature movement, brain waves (EEG) and steering wheel grip may all be monitored.

Estimations of the approximate reductions expected with lane driver monitoring systems in Germany (assuming 70% penetration of the passenger vehicle fleet) were reported by eSafety Forum (2005). It was expected that 50% of fatigue-related crashes would be affected, leading to a 35% reduction in these crashes. This would equate to a 2.9% reduction in all crashes.

Fatigue warning systems (FWS) have been proposed as specific countermeasures to reduce collisions associated with driver fatigue. These devices employ a variety of techniques for detecting driver drowsiness while operating a vehicle and signal a driver when critical drowsiness levels are reached. However, the detection of driver fatigue using valid, unobtrusive and objective measures remains a significant challenge. Detection techniques may use lane departure, steering wheel activity, ocular or facial characteristics. Several authors point out that fatigue warning systems may result in driver behavioural adaptation (Sagberg, 1999). A possible negative effect of in-car warning systems may be that driver's use them to stay awake and drive for longer periods rather than stopping and have a nap; i.e. risk compensation by relying too much on the safety system.

This was confirmed by a study of Vincent, Noy and Laing (1998). They evaluated a fatigue warning system that measured ocular and face monitoring, vehicle speed, steering position and lane position. They found the users of the system did not take more or longer breaks and did not show different fatigue levels to controls. Drivers generally ignored the FWS signals received. The physical aspect of the warning signals used in the study had no impact on driver fatigue levels. Voluntary rest stops, lasting on average 30 minutes, only had a minor impact on decreasing driver fatigue with short-lived effects. The authors concluded that voluntary breaks were ineffective in substantially counteracting the effects of fatigue associated with prolonged driving at night. Whereas normally rested drivers may successfully use breaks to prevent or postpone fatigue during a daytime drive (Philip et al., 2005), the use of breaks seems less successful in reducing fatigue resulting from prolonged driving at night and associated sleep loss.

In recent years, there is large body of research into the operation of various fatigue monitoring systems. Below some studies are described.

Jagannath & Balasubramanian (2014) studied several possible indicators of the onset of early physical and mental driving fatigue in a static simulator study. Twenty male participants first acquired 30 minutes experience with driving in the simulator, and after a 20 minutes break they then commenced a 60 minute drive in a simulated monotonous highway environment with low traffic density. The researchers took surface measurements of EMG signals from muscle groups, measurements of brain activities (EEG), measurements of seat interface pressure, heart rate, oxygen saturation and systolic and diastolic blood pressures. Results from sEMG showed significant physical fatigue in back and shoulder muscle groups. The study showed that there is a significant change in postural muscle-groups such as latissimus dorsi medial and erector spinae during monotonous driving. Subjective evaluation of fatigue also showed physical discomfort among drivers at the end of 60 min of driving, especially in shoulders and back muscle groups. Results also showed significant change in bilateral pressure distribution on thigh and buttocks region during the study. EEG showed a significant increase of alpha and theta activities and a significant decrease of beta activity during monotonous driving. Heart rate decreased significantly during monotonous driving task. These findings demonstrate the use of multimodal measures to assess early onset of fatigue. According to the researchers significant deviation of these measures from initial or alert baseline should be observed as a symptom of early onset of fatigue.

In an 8-week Australian field study with army reserve personnel drivers, Aidman et al. (2015) tested the Optalert Alertness Monitoring System (OAMS). This system utilizes infra-red reflectance oculography to monitor eyelid movements and to detect drowsiness. The system has

been previously used to detect driver drowsiness in mining and road transport industries and pilot drowsiness in aviation. In a repeated measures crossover design the drivers drove about half of the time in a feedback condition and the other half in a no-feedback condition. In this design the participants were therefore their own controls. The provision of real-time feedback resulted in reduced drowsiness and improved alertness and driving performance ratings. The effect was small, but robust after controlling for time of day and driving task duration.

In a German survey, Karrer-Gauss & Zawistowski (2013) asked questions on drivers' experiences with driver fatigue monitoring systems and their compliance with systems advice. The results were not very positive as to the effectiveness of the systems then in use. Nearly half of the drivers (45%) experienced at least one false alarm and over half of the drivers (61%) stated that the system did not warn them despite their actual fatigue. Interestingly of the 59 drivers who had received a warning 24 responded that the warning was appropriate, but only 14 of the 24 complied with the warning and took a break shortly afterwards. Ten of the participants who believed the warning was appropriate, continued the drive. Irrespective of the correctness of the fatigue detection warning, two-thirds of drivers (66%) who received a warning, did not comply with it. Also, the majority of drivers (86%) did not change the number of breaks they took on a trip, as a result of having a fatigue monitoring system in their vehicle; in similar fashion, a majority (59%) described no changes in their fatigue awareness, as a result of having a fatigue warning system. All in all, these results suggest that there is much room for improvement in how accurate fatigue monitoring systems are and in how much effect it has on driving behavior.

Reviewing the literature on neurophysiological measurements of mental workload, fatigue and situation awareness in pilots and drivers, Borghini et al (2014) conclude that at the moment only a few mental states, related to high workload or high drowsiness, can be easily estimated from drivers and pilots with the use of offline analysis (i.e. analysis of neurophysiological data *after* the data have been recorded instead of *during* data recording). In view of the fast scientific developments in this area, these authors predict that the online detection of such mental states (i.e. detection during the mental activity itself) will be reached before 2020.

8.5 Legislation and enforcement

EU Legislation

ETSC (2010) describes the main EU legislation with regard to driver fatigue. The Working Time Directive (Directive 2002/15/EC) which applies to all mobile workers (excluding the self-employed) performing road transport activities limits weekly working time to 48 hours, although weekly hours may increase exceptionally to a maximum of 60. The Directive also entails restrictions on night working and enforces rest breaks.

The Driving Time and Rest Period Regulation (EC 561/2006) aims to introduce clearer and simpler rules about driving times, breaks and rest periods for professional drivers operating both in national and international transport. The basic principle is that by requiring a regular weekly rest period at least once per two consecutive weeks and a daily rest period, social conditions for drivers and road safety should be improved.

Legislation also covers recording equipment (tachographs) with Regulation EEC 3821/85 amended in 1998 to introduce digital tachographs. Directive 2006/22/EC identified minimum

Fatigue

levels of enforcement required to secure compliance with the rules set out in the Driving Times and Rest Periods and the Tachograph Regulations. It provides common methods to undertake roadside checks and checks at the premises of undertakings as well as promoting cooperation between Member State authorities in charge of road transport enforcement. The European Traffic Police Network (TISPOL) for instance runs targeted campaigns throughout Europe to enforce traffic rules concerning trucks, including driver's hours and tachograph offences (for information about the 2008 'Operation Truck' campaign visit: <http://www.tispol.org/node/3602>).

EU legislation covering vehicle safety has also an impact on work-related road safety as under the new Vehicle Safety Regulation 661/2009 trucks and other heavy vehicles must be fitted with Lane Departure Warning (LDW) Systems as of 2013. Lane Departure Warning devices can be effective in managing drivers experiencing sleepiness. Lane changing represents 4 to 10% of all crashes. Here too the emphasis is on heavy vehicles.

As part of the European ITS package, a Directive proposal includes developing specifications for ITS applications and services. Appropriate measures on secure parking places for trucks and commercial vehicles and on telematics-controlled parking and reservation systems is one of only four chosen priorities. Once in place this will better allow commercial drivers to plan their journeys and rest.

New EU Legislation 2007: The Driving Time and Rest Period Regulation

Under previous legislation in the EU it had been legally possible for truck drivers to drive almost nine hours with a break period of only 15 minutes. To improve road safety and the working conditions of drivers, the European Parliament and the Council of the European Union adopted regulation (EC) No 561/2006 laying down provisions concerning driving and working hours of drivers in road transport. This regulation entered into force in April 2007 and applies to drivers of vehicles with a total mass of at least 3,5 tonnes and vehicles constructed to carry more than nine persons. On various sites and booklets the legislation is explained (e.g. RSA, 2008)

According to the new regulation, road transport undertakings can be made liable for infringements committed by drivers. Neglecting regulatory constraints when scheduling driving and working hours of drivers may lead to infringements and/or delayed arrival times due to required breaks and rest periods which have not been scheduled. Consequently, road transport undertakings must ensure that truck driver schedules comply with regulation (EC) No 561/2006. This regulation distinguishes between four driver activities: rest periods, breaks, driving time, and other work.

The regulation places constraints on the minimum duration and frequency in which rest periods must be taken. A weekly rest period of at least 45 hours must start no later than 144 hours after the end of the previous weekly rest period. Alternatively, a reduced weekly rest period of at least 24 hours may be taken. However, before the end of the third calendar week (i.e. the week starting Monday 0.00 hours and ending Sunday 24.00 hours) after the reduced weekly rest period has been taken, the reduction must be compensated by an equivalent period of rest attached to another rest period of at least nine hours. In any two consecutive calendar weeks at least two weekly rest periods must be taken and the duration of at least one of them must be of 45 hours or more. Weekly rest periods falling in two calendar weeks may be counted in either week, but not in both.

Regular daily rest periods of at least 11 hours must be completed within each period of 24 hours after the end of the previous daily rest period or weekly rest period. This regular daily rest period may be replaced by a reduced daily rest period of at least nine hours. However, a driver may have at most three reduced daily rest periods between any two weekly rest periods. Alternatively, a regular daily rest period may be replaced by two periods, the first of which must be a rest period of at least three hours and the second a rest period of at least nine hours. A daily rest period may be extended beyond 24 hours after the end of the previous daily rest period or weekly rest period. Depending on the amount of extension the rest period may be interpreted as a weekly rest period.

The accumulated driving time between the end of a daily or weekly rest period and the begin of the next daily or weekly rest period must not exceed nine hours. However, twice during a calendar week the daily driving time may be extended up to at most ten hours. The accumulated working time during a calendar week must not exceed 60 hours. The accumulated driving time during a calendar week must not exceed 56 hours. The total accumulated driving time during any two consecutive calendar weeks must not exceed 90 hours. In any period of four months, the average working time during a calendar week must not exceed 48 hours.

A full break is completed after an uninterrupted break of at least 45 minutes or after a break of at least 30 minutes which is preceded by a break of at least 15 minutes. A driver may drive for at most four and a half hours without taking a rest period or a full break.

US legislation

On 28 April 2003 the Federal Motor Carrier Safety Administration (FMCSA) published a revised set of hours-of-service (HOS) regulations concerning the HOS of commercial-vehicle drivers. These published regulations were amended on 30 September 2003 and implemented on 4 January 2004. One central component to the revision was a 2-h extension of off-duty time from 8 to 10 h. One rationale given in an FMCSA posting in the Federal Register (2005) was the additional 2 hours of off-duty time would provide drivers with “substantially more opportunity

to obtain restorative sleep” (Hanowski et al., 2007). Research indicated that the quantity of sleep obtained by truck drivers after legislation was significantly improved (Hanowski, 2007).

The various laws concerning drowsy driving in the USA are summarised on the site of the National Conference of State Legislatures (NCSL).

See: <http://www.ncsl.org/research/transportation/summaries-of-current-drowsy-driving-laws.aspx>

Australian legislation

On 29 September 2008 new Heavy Vehicle Driver Fatigue (HVDF) laws were introduced in South Australia and in all other states and territories (except WA and the ACT). The new laws consider the health and well-being of heavy vehicle (including bus) drivers, aiming to help drivers get home safely by requiring that all parties in the chain-of-responsibility take ‘reasonable steps’ to prevent driver fatigue. The new laws stress that the causes of fatigue are a responsibility shared by off-road parties in the supply chain and unrealistic driver schedules and consigner demands and practices are not acceptable.

See http://www.transport.sa.gov.au/freight/driver_fatigue/index.asp

The new laws are intended to:

- promote positive fatigue management systems to ensure the safety of drivers and increase safety for all road users
- monitor the hours that drivers of heavy trucks and buses can spend working (including driving) and resting
- monitor the records that must be kept.

Employers and consignors are responsible for ensuring safe driving practices and may not roster or require a driver to carry out duties that could cause the driver to commit a fatigue or speeding offence. Offences under the new laws are classified according to the actual level of risk and the greater the risk involved, the more significant the penalties. Penalties range from an infringement notice to court imposed penalties and loss of demerit points. Compliance with the laws will help employers meet their obligations under Occupational Health Safety & Welfare (OHS & W) legislation.

There are three different hours options:

- Standard Hours (SH) allows work for a maximum of 12 hours a day.
- Basic Fatigue Management (BFM) allows a maximum of 14 hours daily work.
- Advanced Fatigue Management (AFM) allows operators to nominate the number of daily working hours needed, up to an outer limit of 16 hours.

In Tasmania, new fatigue management laws were introduced on 30 March 2015 (Tasmanian Government, 2015). The new Heavy Vehicle National Law (HVNL) brings changes to work and rest limits for heavy vehicle drivers and the management of driver fatigue. The new laws apply to both the drivers and operators of trucks and buses and all parties in the supply chain are to take reasonable steps to ensure fatigue is managed. The fatigue laws apply to a truck or combination with a GVM exceeding 12 tonnes and to a bus with a seating capacity of more than 12 (including the driver). At an operational level, the greatest change for Tasmanian industry relates to work and rest times under 'Standard Hours'. Under previous arrangements in Tasmania, for a 24 hour period, drivers were allowed 12 hours of drive time plus 2 hours of non-

driving work time. Under Standard Hours under the national law, drivers have 12 hours of work time – including both driving and non-driving work. Thus the maximum amount of driving time stays the same at 12 hours, but drivers are losing two hours of work time. This brings Tasmania into line with the other Australian states that have already had this in place for some years.

On a more strategic level, one of the changes under the new law is the introduction of ‘chain of responsibility’, which recognises that everyone involved in the supply chain – not just the driver or operator – has a role in fatigue management and compliance with transport law (Tasmanian Government, 2015). The chain of responsibility applies to speed, mass dimension and loading, as well as fatigue. For example the chain of responsibility applies to the following situations:

- Heavy vehicle driver breaches of fatigue management requirements (or speed limits)
- Schedulers placing unrealistic timeframes on drivers, with the potential for drivers to exceed their work hours
- Operators who do not provide drivers with an appropriate sleep environment if their work involves sleeping away from home. An appropriate sleep environment might include an approved sleeper cab and access to rest stops.

International comparison of legislation

Jones et al. (2005) compared legislation concerning fatigue in Australia, Canada, United Kingdom and USA against eight criteria based on their established relationship with fatigue: time of day; the 24-hour rhythm; duration of sleep; quality of sleep; predictability of sleep; sleep deprivation; duration of task performance; and presence of short breaks. The authors conclude that for neither of four transport modalities (road, air, water, rail) legislation takes these criteria fully into account. They argue for a mix of prescriptive legislation and non-prescriptive guidelines (e.g. fatigue management programs) in order to obtain the best counter-fatigue strategy.

8.6 New possibilities for enforcement

In the future police enforcement of fatigued driving will become possible once reliable tests of sleepiness in the field are available. In recent years, progress has been made in the development of such practical tests to detect driver fatigue or sleepiness. Methods to test fatigue or sleepiness have concentrated on eyelid measures, measurement of physical balance and measurement of pupillary oscillations.

Peters et al. (2014) investigated the use of the pupillographic sleepiness test (PST) during routine police speed check controls of truck drivers in Southern Germany. During the test, subjects wore goggles with infrared transmitting filter glasses and fixate a weak red light, which was the only thing the subject is able to see through the goggles. Pupillary oscillations were registered, quantified and analysed automatically by the system, and results given relative to the initial pupil size (Peters et al., 2014).

The net examination time for the PST was 11 minutes, allowing it to be performed within the time required for the police to check on load, truck and papers. The study results showed that despite influential factors such as the stress of a police control itself, and free coffee and nicotine consumption (which is excluded 4h before the recording in the clinical setting), drowsiness could be detected by the PST. Of the 136 completed recordings, 126 (92 %) were usable. The method therefore appears to be robust.

The main aim of this study was to examine the feasibility of performing the PST in the setting of police control stop checks. To carry out the measurements, the police requires a sufficient time window for the recording, as well as suitable premises. The complete test can be performed within 15 min, no longer than the time required carrying out a police control spot check. The test itself needs a quiet room, which can be darkened, either at a service station or in a smaller, transportable quarters, e.g. in an emergency vehicle. The feasibility of the method and results in car drivers from pilot tests at German roadhouses has been published previously (mentioned in Peter et al, 2014).

Another possible roadside test for measuring drowsiness was developed and tested by Forsman et al. (2014). These researchers sought to evaluate the feasibility of using a force platform test of postural control as a breathalyzer-like drowsiness-test at the roadside. In their study seventy-one commercial drivers stopped by at specific measurement sites and volunteered to participate. The researchers tested postural control with a computerized force platform, on which the drivers stood eyes open while it sampled body center-of-pressure excursions at 33Hz for 30s. The drivers also completed the Karolinska Sleepiness Scale (KSS) and records were made of each driver's wake up time, time on task, and time of testing. It appeared that postural control and KSS scores correlated highly ($r=-0,88$, $P=0,04$). These and other results indicate that the force platform test was able to identify drivers, whose impairment in postural control was drowsiness-related. Specifically, the test identified the few drivers in this roadside sample whose wake- and work histories resembled a night shift schedule. The researchers concluded that the method with some further development may provide a drowsiness test for roadside surveillance.

8.7 Fatigue management programs

'Fatigue management systems' aim to prevent fatigue-related crashes by introducing a set of inter-related measures, at different levels of the organization. These measures are directed at the management, the planning section, and the drivers. Typically, the measures include special driver training, new procedures, improved trip planning and feedback on crashes. Information about the effectiveness of these systems is still scarce. "Fatigue Management" programs in Australia and the United States are based on several starting points (SWOV Factsheet Fatigue in traffic: causes and effects):

- First of all by supporting the application of maximum driving and resting hours companies may take the human need for rest and sufficient night-time sleep into account.
- As a consequence, haulage companies have to plan the work so that drivers can keep to the rules.
- Compliance control of these rules remains important. In addition, haulage companies should also have a certain responsibility for informing their drivers about the causes and results of fatigue.
- If possible, company programs should pay attention to the influence of personal living circumstances (life style) of individual drivers and their own responsibility.
- Another possible task of haulage companies is screening drivers for sleeping disorders, especially sleep apnea.

Expert opinion identifies a number of factors that determine the success of these systems (Jettinghoff et al., 2005):

Fatigue

- Management and drivers have a positive view on the importance and usefulness of the fatigue management system;
- Somebody actively steers the process and takes responsibility for progress;
- Management clearly points out the importance of several fatigue-related measures in reducing risk;
- Clear company procedures and guidelines regarding safe behaviour;
- Feedback on crashes is used to increase insight into the problem of fatigue;
- Driver training is part of a progressive learning cycle.

The ideas about a Safety Culture for haulage companies clearly also fit in to this. See Erso web texts on Work-related road safety and Erso web text on Integrating road safety into other policy areas.

A Driver Fatigue Management Plan (DFMP) sets out the requirements and procedures relating to how a company will schedule trips; roster drivers; establish a driver's fitness to work; educate drivers in fatigue management; manage incidents on or relating to commercial vehicles; and establish and maintain appropriate workplace conditions.

Research may provide valuable information on driving and rest schedules. Driving schedules should be planned to minimise exposure to prolonged driving under monotonous conditions during the more vulnerable times of the day and night (Horne & Reyner, 2001). A study among professional long-haul drivers showed that a 3-hour napping opportunity in the afternoon preceding a nightshift has beneficial effects on driving performance and alertness, measured up to 14 hours later (Macchi et al., 2002). A study among long-haul truck drivers indicated that single drivers were more frequently involved in critical incidents while exhibiting extreme drowsiness than were team drivers by a factor of 4 to 1 (Klauer et al., 2003).

As part of fatigue management, organizations may implement biomathematical models to predict fatigue-related risks associated with hours of work. Based on empirical research amongst workers in the train industry, Darwent et al. (2015) argue that fatigue models should be seen as tools that provide sleep information rather than tools for predicting fatigue-related risks. The emphasis on sleep information makes it easier to communicate results to non-experts (workers) and it focuses the attention on the importance of scheduling adequate sleep opportunities for all employees. The problem with providing risk information is that there are no universally-applicable risk-based criteria to classify outputs of biomathematical models as safe versus unsafe.

Box 7. Fatigue management as part of safety culture

The importance of organizational culture for safety programmes, including fatigue management programs, has been supported by empirical research (Bomel, 2004; Arnold & Hartley, 2001).

Fatigue risk management must be an integral part of a company's safety policy and it must be open, transparent and address the following elements (Gander et al., 2011): Commitment to the Fatigue Risk Management Policy from the highest levels of the organization.

- A specified line of accountability for fatigue risk management in the organization.
- Definition of the responsibilities of company management and employees.
- Identification of the work groups covered by the FRMS.
- Terms of reference for the Fatigue Management Steering Committee (FMSC), including frequency of meetings.
- Identification of fatigue reporting mechanisms.
- Policies for identifying and managing employees who are fatigued to an extent that represents a safety risk, including considering provision for opting out of an assignment.
- Commitment to provide training and resources in support of the Fatigue Risk Management Policy.
- Commitment to act on recommendations on fatigue risk management from internal audit.

An FRMS is a Safety Management System (SMS), or part of an SMS, focused on managing fatigue risk. Within an FRMS, fatigue is managed in a data-driven and flexible manner appropriate to the level of risk exposure and the nature of the operation (Fourie et al., 2010). An FRMS considers multiple sources of fatigue and provides integrated, multiple defenses against fatigue risk. To be effective, an FRMS requires clear lines of accountability, a just culture and the integration of fatigue risk management into a company's everyday business (Fourie et al., 2010).

Road transport and aviation regulators in Australia and New Zealand have led the move away from prescriptive Hours of Work (HoW) limitations towards adopting fatigue risk management systems across transport industries (Fourie et al., 2010). In September 2008, the new Heavy Vehicle Driver Fatigue regulations, was introduced, which replaced the HoW limitations specified by the Road Transport Reform (Driving Hours) Regulations of 1999. The new regulations, developed by the National Transport Commission (NTC), are an example of outcome-based legislation. Rather than being required to comply with prescriptive rules, companies are required to focus on an outcome (managing fatigue). The regulations were also an attempt to nationalize fatigue management and HoW limitations in a country where these regulations may differ per individual state and territory (Fourie et al., 2010)

The new regulations differ from traditional regulatory approaches to driver fatigue in three key ways. Firstly, they emphasize that all operators have a duty to manage their employees' fatigue, consistent with health and safety legislation. Secondly, chain of responsibility legislation determines that the responsibility to manage fatigue is not solely a responsibility of the driver and the operating company. The legislation identifies a number of parties in the supply chain in road transport who could influence fatigue risk, including the prime contractor, scheduler, consignor, consignee and loading manager, all of whom have a legal responsibility for preventing driver fatigue. Finally, the new regulations constitute a multi-model approach in that organizations can follow standard HoW or, if they demonstrate they are managing fatigue in a sophisticated manner, they can work according to more flexible HoW (Fourie et al., 2010).

8.8 Specific company management interventions

ETSC (2008) describes several recent company management interventions to reduce work-related fatigued driving.

Tyvi Freight, Finland

The Finnish Tyvi freight transport company developed an online management system for the use of the management of regular working hours and working shifts along many other operations management applications. It is an intranet and internet-based system and enables to combine all information needed in the company in real time and therefore allow real-time management through bi-directional communication between the employer and the driver. The online system helps Tyvi to improve its service to customers, but it also enables improved drivers' working hours, and is thus a tool for enhancing workers' well-being at work. The instrument allows the company to plan more "normal" working hours for drivers, i.e; shorter working days and more predictable, regular shifts. The system includes work and customer instructions, service instructions, laws and regulations concerning the transport business, and instructions for drivers on giving daily reports to the company.

Swisscom Schweiz AG

Swisscom has launched a fatigue and distraction campaign in 2010 targeting all employees (4.000 fleet cars). It has adopted a Vision Zero serious and fatal crashes. The goals are to improve road safety of employees; prevent damage to their image and operational disturbance and reduce vehicle damage. The measures adopted include disseminating information to all employees, sending a newsletter to fleet car drivers, education and instruction of multipliers. This includes branch managers and safety agents. Exhibition with panels in buildings are also arranged as are quizzes and prizes, involving all employees and apprentices, some of whom attend the exhibition.

United Kingdom

A major UK mobile telecommunications provider has a specific policy working around tired driving. Below is an extract from their current Driving at Work policy:

- Tiredness kills – Take breaks at least every 2 hours or 100 miles, get out of car and walk about for at least 10 minutes
- When travelling on a long haul flight you should not drive on arrival at your destination until you are absolutely sure that you are over "jet lag" or the general tiredness brought on by travel. It is recommended that you take a taxi or are met by a friend, colleague or family member.
- Driving excessive distances in one day (e.g. 3hr drive with 6-8 hours in the office then a further 3 hour drive), journeys of this type should be avoided; make an overnight stay to break the working day.

8.9 Need for further knowledge on countermeasures

Until recently, very little research on the cost-effectiveness of measures to reduce the number of fatigue-related crashes has been carried out (an exception is Sassani et al., 2004). The objective determination of costs and benefits of fatigue management is seen internationally as one of the challenges in fatigue research during the coming years, particularly if fatigue detection systems are to be implemented on a large scale.

Besides determining the cost-effectiveness of measures, further development of useable and reliable fatigue detection systems and the accompanying criteria is an on-going subject of research in Europe. Determining the extent of the fatigue problem for road safety seems to be regarded as less relevant in Europe. One reason may be the consideration that it is sufficiently well known that fatigue is an important factor. In spite of this, a well-designed, large-scale epidemiological study on the risk-increasing effects of fatigue would be an important contribution to knowledge about this problem.

8.10 Conclusions

- Publicity campaigns may help educate the general public about the problem of driver fatigue and possible countermeasures. Care should be taken to provide drivers with clear and practical messages. It should be quite clear that drivers should prevent fatigue rather than try to overcome it, and that they should stop driving when they feel very tired.
- Within transport companies, fatigue management plans may be successful in combating driver fatigue provided that they are endorsed at all company levels and they are part of a more general road safety culture.
- Further improvement in legislation concerning driver fatigue will take time, but is a necessary part of the total solution. The current EU legislation does not take into account all factors relevant to fatigue and EU Member States legislations are highly variable in terms of legal rules for driving fitness for persons with a sleeping disorder.
- Progress has been made in the development of practical field tests of driver fatigue that may play a supporting role in the enforcement of fatigued driving.
- In the future, driving assistance systems may warn the driver when the driver or vehicle show signs of fatigue-induced behaviour, but in the near term these systems need to be more fully developed yet, incorporating acceptance and use by drivers. It is predicted by experts that reliable online detection of high drowsiness states of drivers is achievable before 2020.
- Knowledge about cost-benefit of various countermeasures is needed.

References

AAA Foundation for Traffic Safety research report) Virginia Tech Transportation.

Accident Analysis and Prevention, 43, p. 797–803 accidents in sleep apnea patients. Sleep: Journal of Sleep Research & Administration, Office of Research and Analysis, Washington.

Aidman, E., Chadunow, C., Johnson, K., Reece, J. (2015) Real-time driver drowsiness feedback improves driver alertness and self-reported driving importance. Accident Analysis and Prevention, 81, pp. 8-13.

Åkerstedt, T. & Gillberg, M. (1990) Subjective and objective sleepiness in the active individual. International Journal of Neuroscience, 1990, 52, pp. 29-37.

Åkerstedt, T. & Kecklund, G. (2001) Age, gender and early morning highway accidents. Journal of Sleep Research, 10(2), pp. 105-110.

Åkerstedt, T. (1995a) Work hours, sleepiness and accidents: introduction and summary. Journal of Sleep Research, 4(2), pp.1-3.

Åkerstedt, T. (1995b) Work hours, sleepiness and the underlying mechanisms. Journal of Sleep Research, 4(2), pp. 15-22.

Åkerstedt, T. (1995c) Work hours and sleepiness. Neurophysiologie Clinique, 25(6), pp. 367- 375.

Åkerstedt, T., Peters, B., Anund, A. & Kecklund, G. (2005) Impaired alertness and performance driving home from the night shift: a driving simulator study. Journal of Sleep Research, 14, pp. 17-20.

Amárach Research (2009) Long journeys and driving while tired. Road Safety Authority, Galway.

Amundsen, A.H. & Sagberg, F. (2003) Hours of service regulations and the risk of fatigue- and sleep-related road accidents. TOI, Oslo.

Anselm, D. & Hell, W. (2002) Einschlafen am Steuer: eine häufig unterschätzte Unfallursache. In: Verkehrsunfall und Fahrzeugtechnik, Heft 3, pp. 62-66.

Armstrong, K., Obst, P., Banks, T., Smith, S. (2010) Managing driver fatigue: education or motivation? Road & Transport Research, 19, pp 14-20.

Arnedt, J., Gerald, J., Munt, P., & MacLean, A. (2001) How do prolonged wakefulness and alcohol compare in the decrements they produce on a simulated driving task? Accident Analysis and Prevention, 33, pp. 337–44

Arnold, P.K. & Hartley, L.R. (2001) Policies and practices of transport companies that promote or hinder the management of driver fatigue. Transportation Research Part F, 4, 1- 17.

- Axelsson, J. (2005) Long shifts, short rests and vulnerability to shift work. Doctoral Dissertation. Department of Psychology, Stockholm University, Stockholm Accessed 29 January 2008: <http://www.diva-portal.org/su/theses/abstract.xsql?dbid=453>.
- Balkin, T.J., Horrey, W.J., Graeber, R.C., Czeisler, C.A., Dinges, D.F. (2011) The challenges and opportunities of technological approaches to fatigue management. *Accident Analysis and Prevention* 43, pp. 565–572.
- Barr, L.C., David Yang, C.Y., Hanowski, R.J. & Olson, R. (2011) An Assessment of Driver Drowsiness, Distraction, and Performance in a Naturalistic Setting. FMCSA-RRR-11-010. U.S. Department of Transportation Federal Motor Carrier Safety Administration, Washington.
- Barrett, P., Horne, J., & Reyner, L. (2004) Sleepiness combined with low alcohol intake in women drivers: Greater impairment but better perception than men? *Sleep*, 27, pp. 1057–62.
- Berg, van den, J. & Landström, U (2006) Symptoms of sleepiness while driving and their relationship to prior sleep, work and individual characteristics. *Transportation Research Part F*, 9, pp. 207–227.
- Blom, D.H.J. & Pokrony, M.L.I. (1985) Accidents of bus drivers An epidemiological approach. Doctoral dissertation. Nederlands Instituut voor Praeventieve Gezondheidszorg TNO, Leiden.
- Bomel Ltd. (2004) Safety Culture and Work-Related Road Accidents, Road Safety Research Report No. 51. Department for Transport, HMSO, London.
- Borghini, G., Astolfi, L., Vecchiato, G., Mattia, D., Babiloni, F. (2014) Measuring neurophysiological signals in aircraft pilots and car drivers for the assessment of mental workload, fatigue and drowsiness. *Neuroscience and Biobehavioral Reviews*, 44, pp. 58-75.
- Brake road safety charity (2011) Press release 'One in eight drivers nodded off at the wheel in the past year, reveals charity', July 13th 2011, a survey of 1,000 drivers conducted by Redshift Research for Brake and Cambridge Weight Plan in June 2011 Excel research sent to SWOV July 15th 2011. Brake road safety charity, Huddersfield, UK.
- Brookhuis, K., De Waard, D. & Mulder, B. (1994) Measuring driving performance by car- following in traffic. *Ergonomics* 37, pp. 427–434.
- Brown, I. D. (1994) Driver fatigue. *Ergonomics*, 1994, 36, pp. 298-314.
- Brown, I. D. (1995) Methodological issues in driver fatigue research. In: L. Hartley (Ed), *Fatigue and driving: driver impairment, driver fatigue and driving simulation*. , pp. 155-166. Taylor and Francis, London.
- Buxton, S. & Hartley, L. (2001) Napping to prevent fatigue: A policy. Insurance Commission of Western Australia: 2001 Conference on Road Safety 'Road safety: gearing up for the future', 31 August 2001, Perth.

Catarino, R., Spratley, J., Catarino, I., Lunet, N. & Pais-Clemente, M. (2014) Sleepiness and sleep-disordered breathing in truck drivers. *Sleep Breath*, 18, pp. 59-68.

Chakraborty, M., & Hossain, A.N. (2014) Implementation of Computer Vision to Detect Driver Fatigue or Drowsiness to Reduce the Chances of Vehicle Accident. International Conference on Electrical Engineering and Information & Communication Technology (ICEEICT), 10-12 April 2014. pp. 1-5.

Charbotel, B., Chiron, M., Martin, J.L. & Bergeret, A. (2001) Work related road accidents in France. *European Journal of Epidemiology*, 17(8), pp. 773-778.

Chen, C. en Xie, Y. (2014) The impacts of multiple rest-break periods on commercial truck drivers's crash risk. *Journal of Safety Research*, 48, pp. 87-93. .

Clarke, D.D., Ward, P., Bartle, G. & Truman, W. (2005). An In-depth Study of Work-related Road Traffic Accidents. Department of Transport, London. Accessed 29 January 2008: http://www.orsa.org.uk/guidance/pdfs/indepth_study_work_related_road_accidents.pdf

Connor, J., Norton, R., Ameratunga, S., Robinson, E., Wigmore, B., & Jackson, R. (2001) Prevalence of driver sleepiness in a random population-based sample of car driving. *Sleep*, 24, pp. 688-694.

Connor, J., Whitlock, G., Norton, R. & Jackson, R. (2001) The role of driver sleepiness in car crashes: a systematic review of epidemiological studies *Accident Analysis and Prevention*, 33, pp. 31-41.

Corbett, C. (2003) *Car Crime*, Chapter 9, pp. 177-189. (Crime and Society Series) Willan Publishing, Devon, UK.

Craft, R. (2007) The Large Truck Crash Causation Study. Analysis Brief: LTCCS crashes. *Journal of Clinical Sleep Medicine*, 2008, 15, pp. 533-535.

Cummings, P., Koepsell, T.D., Moffat, J.M. & Rivara, F.P. (2002) Drowsiness, counter-measures to drowsiness, and the risk of a motor vehicle crash. *Injury Prevention*, 7, pp. 194- 199.

Danner, F., & Phillips, B. (2008) Adolescent sleep, school start times, and teen motor vehicle.

Darwent, D., Dawson, D., Pasterson, J.L. Roach, G.D. & Ferguson, S.A. (2015) Managing fatigue: It really is about sleep. *Accident Analysis and Prevention*, 82, pp. 20-26.

Delhomme, P., Vaa, T., Meyer, T., Harland, G., Goldenbeld, C., Järmark, S., Christie, N. & Rehnova, V. (1999) Evaluated Road Safety Media Campaigns: An Overview of 265 Evaluated Campaigns and Some Meta-Analysis on Accidents. Gadget project, Work package 4, contract no. RO-97-SC.2235. Project funded by EC and partners under EU 4th Framework Programme. INRETS, France.

Department of Consumer and Employment Protection (2003) Developing a fatigue management plan for commercial vehicle drivers and operators. Western Australia, Cloisters Square Accessed 4 February 2008:

<http://www.safetyline.wa.gov.au/pagebin/mechhazd0025.pdf>

Desmond, P.A. & Matthews, G. (2009) Individual differences in stress and fatigue in two field studies of driving. *Transportation Research Part F*, 12, pp. 265-276.

Desmond, P.A. (1998) Driver fatigue: performance and state. In: L. Hartley (red.) *Managing fatigue in transportation*. Oxford, Elsevier Science, pp. 65-76.

Di Milia, L., Smolensky, M.H., Costac, G., Howarth, H.D., Ohayone, M.H., & Philip, P. (2011) Demographic factors, fatigue, and driving accidents: An examination of the published literature. *Accident Analysis and Prevention*, 43 pp. 516-532.

Dinges, D. (1995) An overview of sleepiness and accidents. *Journal of Sleep Research*, 4(2), pp. 4-14.

Dinges, D. F. & Kribbs, N. B. (1991) Performing while sleepy: effects of experimentally induced sleepiness. In: Monk, T. H. (Ed.) *Sleep, Sleepiness and Performance*, 97-128. Wiley, Chicester.

Dinges, D.F., & Mallis, M.M. (1998) Managing fatigue by drowsiness detection: Can technological promises be realized? In: Hartley, L. (Eds.) *Managing Fatigue in Transportation*, pp. 209-230. Elsevier Science Ltd., Kidlington, Oxford, UK.

Dingus, T. A., Klauer, S. G., Neale, V. L., Petersen, A., Lee, S. E., Sudweeks, J., Perez, M. A., Hankey, J., Ramsey, D., Gupta, S., Bucher, C., Doerzaph, Z. R., Jermeland, J. & Knippling, R.R. (2006) *The 100-Car Naturalistic Driving Study: Phase II – Results of the 100- Car Field Experiment*. DOT HS 810 593. National Highway Traffic Safety Administration, Washington, DC Accessed 4 February 2008: <http://www-nrd.nhtsa.dot.gov/departments/nrd-13/driver-distraction/PDF/100CarMain.pdf>.

Driving Study Data [NHTSA Report No. DOT HS 810 594] Virginia Tech driving: a simulator study. *Physiology and Behavior* 94, 448–453.

Du, H., Zhao, X., Zhang, X., Zhang, Y. & Rong, J. (2015) Effects of Fatigue on Driving Performance Under Different Roadway Geometries: A Simulator Study, *Traffic Injury Prevention*, 16:5, 468-473.

Ellen, R.L., Marshall, S.C., Palayew, M., Molnar, F.J., Wilson, K.G. (2006) *Systematic eSafety Forum (2005) Final report and recommendations of the implementation road map working group*.

ETSC (1998) *Forging roadsides*. ETSC, Brussels Accessed 8 April 2008: http://www.etsc.be/oldsite/bri_road5.pdf.

ETSC (2001) *The role of driver fatigue in commercial road transport crashes*. European Transport Safety Council ETSC, Brussels Accessed 15 January 2008: <http://www.etsc.be/oldsite/drivfatigue.pdf>.

ETSC (2010) "PRAISE": Preventing Road Accidents and Injuries for the Safety of Employees. European Transport Safety Council ETSC, Brussels.

Federal Motor Carrier Safety Administration (2000) Hours of Service of Drivers; Driver rest and sleep for safe operations. Department of Transportation 49 CFR Parts 350, 390, 394, 395 and 398, Washington, DC.

Feyer, A.M., Williamson, A. & Friswell, R. (1997) Balancing work and rest to combat driver fatigue: an investigation of two-up driving in Australia. *Accident Analysis and Prevention* 29, 541–553.

Filtness, A.J., Reyner, L.A. and HORNE, J.A., (2012) Driver sleepiness: comparisons between young and older men during a monotonous afternoon simulated drive. *Biological Psychology*, 89 (3), pp. 580-583.

Firestone, R.T. & Gander, P.H. (2010) Exploring knowledge and attitudes of taxi drivers with regard to obstructive sleep apnoea syndrome. *The New Zealand Medical Journal*, 123, pp.24-33.

Fletcher, A., McCulloch, K., Baulk, S.D. & Dawson, D. (2005) Countermeasures to driver fatigue: a review of public awareness campaigns and legal approaches. *Australian and New Zealand Journal of Public Health*, 29(5), pp. 471-476.

Fletcher, A., McCulloch, K., Baulk, S.D., & Dawson, D. (2005) Countermeasures to driver fatigue: a review of public awareness campaigns and legal approaches. *Australian and New Zealand Journal of Public Health*, 29, pp. 471-476.

Fletcher, A. & Mitchell, P. (2011) *Fatigue-Related Risks for Queensland Taxi Drivers*
Final report on the operational and scientific factors related to fatigue in taxi drivers, to inform the possible development of reform, regulation and industry guidelines. Report prepared for Queensland Government.

Folkard, S. (1997) Black times: temporal determinants of transport safety. *Accident Analysis and Prevention*, 29, pp. 417 – 430.

Folkard, S. (1999) *Transport Rhythm And Blues*, PACTS' 10th Westminster Lecture. PACTS, London (quoted from PACTS policy briefing on Fatigue Related Vehicle Crashes 2001 Accessed 20 <http://www.pacts.org.uk/policy/briefings/FATIGUE.htm>)

Forsman, P., Pyykkö, I., Toppila, E., and Hæggström, E. (2014) Feasibility of force platform based roadside drowsiness screening - a pilot study. *Accident Analysis and Prevention*, 62, pp. 186-190.

Fourie, C., Holmes, A., Bourgeois-Bougrine, S., Hilditch, C. & Jackson, P. (2010) *Fatigue Risk Management Systems: A Review of the Literature*. RSSR 110. Department for Transport, London.

Fourie, C., Holmes, A., Hilditch, C., Bourgeois-Bougrine, S., & Jackson, P. (2010) *Interviews with Operators, Regulators and Researchers with Experience of Implementing Fatigue Risk Management Systems*. RSSR 120. Department for Transport, London.

Gander, P., Hartley, L., Pwoel, D., Cabon, P., Hitchcock, E., Mills, A. & Popkin, S. (2011) Fatigue risk management: Organizational factors at the regulatory and industry/company level. *Accident Analysis and Prevention*, 43, pp. 573-590.

Garbarino, S., Nobili, L., Beelke, M., De Carli, F., Ferrillo, F (2001) The contributing role of sleepiness in highway vehicle accidents. *Sleep*, 24, pp. 203-206.

Gershon, P. Shinar, D., Oron-Gilad, T., Parmet, Y., Ronen, A. (2011). Usage and perceived effectiveness of fatigue countermeasures for professional and nonprofessional drivers.

Goldenbeld, C., Davidse, R., Mesken, J. & Hoekstra T. (2011) Vermoeidheid in het verkeer: een studie naar prevalentie en statusonderkenning bij automobilisten en vrachtautochauffeurs. Report 2011-4. Institute for Road Safety Research SWOV, Netherlands, Leidschendam.

Groeger, J.A. (2006) Youthfulness, inexperience, and sleep loss: the problems young drivers face and those they pose for us. *Injury Prevention*, 12, pp. 19-24.

Häkkinen, H. & Summala, H. (2000a) Sleepiness at work among commercial truck drivers. In: *Sleep*, 23(1), pp. 49-57.

Häkkinen, H. & Summala, H. (2000b) Driver sleepiness-related problems, health status, and prolonged driving among professional heavy-vehicle drivers. In: *Transportation Human Factors*, 2(2), pp. 151-171.

Hamelin, P. (1987) Lorry drivers' time habits in work and their involvement in traffic accident. *Ergonomics*, Vol 30, n°9, p.1323, Taylor & Francis, London.

Hamelin, P. (1999) Drivers' working hours in 'Social aspects of road transport. ECMT, Paris

Hamelin, P. (1992) Surveys about professional truck drivers. In: *Selected readings in Transport Survey Methodology*. Eucalyptus Press, Melbourne.

Hanowski, R.J., Hickman, J., Fumero, M.C., Olson, R.L., & Dingus, T.A. (2007) The sleep of commercial vehicle drivers under the 2003 hours-of-service regulations. *Accident Analysis and Prevention*, 39, pp. 1140-1145.

Hargutt, V., Hoffmann, S., Vollrath, M. & Krüger, H.P. (2000) Compensation for drowsiness & fatigue - a driving simulation study. In: *Proceedings of the International Conference on Traffic and Transport Psychology ICTTP*, 4-7 September 2000, Bern, Switzerland.

Härmä, M., Tenkanen, L., Sjöblom, T., Alikoski, T., Heinsalmi, P. (1998) Combined effects of shift work and life-style on the prevalence of insomnia, sleep deprivation and daytime sleepiness. *Scandinavian Journal of Work and Environmental Health*, 24(4), pp. 300-307.

Harrison, W. (2006) *Fatigue and Young Drivers*. Royal Automobile Association of Victoria, Victoria Accessed 29 January 2008:
<http://www.racv.com.au/wps/wcm/resources/file/eb67734a1f070e8/RACV%20Fatigue%20&%20Young%20Drivers%20Report.pdf>.

Haworth, N. (2003) Maximising the road safety impact of advertising. *Australasian Road Research Handbook 2* (Ch. 3). Austroads Incorporated.

Haworth, N.L., Heffernan, C.J. & Horne, E.J. (1989) Fatigue in truck accidents. Report No. 3 Monash University Accident Research Centre, Victoria.

Herman, J., Kafoa, B., Wainiqolo, I., Robinson, E., McCaig, E., Connor, J., Jackson, R., Ameratunga, S. (2014a) Driver sleepiness and risk of motor vehicle crash injuries: A population-based case control study in Fiji (TRIP 12). *Injury, International Journal of the Care of the Injured*, 45, pp. 586–591

Herman, J., Kafoa, B., Wainiqolo, I., Robinson, E., McCaig, E., Connor, J., Jackson, R., Ameratunga, S. (2014b) TRIP Factsheet 7: Driver sleepiness and risk of four-wheel motor vehicle crash injuries in Fiji. Suva: The Fiji School of Medicine.

Horne, J. & Reyner, L. (1999) Vehicle accidents related to sleep; a review. *Occupational and Environmental Medicine*, 56 (5), pp. 289-294.

Horne, J. & Reyner, L. (2001) Sleep-related vehicle accidents: some guides for road safety policies. *Transportation Research Part F*, 4, pp. 63-73

Horne, J., Reyner, L., & Barrett, P. (2003) Driving impairment due to sleepiness is exacerbated by low alcohol intake. *Occupational and Environmental Medicine*, 60, pp. 689– 92.

Horne, J.A. & Reyner, L.A. (1995) Sleep related vehicle accidents. *British Medical Journal*, 310, 565-567.

Horne, J.A. (1992) Stay awake, stay alive. *New Scientist*, 1802, pp. 20-24.

Horrey, W.J., Noy, Y.I., Folkard, S., Popkin, S.M., Howarth, H.D., & Courtney, T.K. (2011) Research needs and opportunities for reducing the adverse safety consequences of fatigue. *Accident Analysis & Prevention*, 43, pp. 591-594.

Horstmann, S., Hess, C.W., Bassetti, C., Gugger, M., Mathis, J., (2000) Sleepiness related accidents in sleep apnea patients. *Sleep: Journal of Sleep Research & Sleep Medicine* 23, pp. 383-389.

Hulst, van der, M., Meijman, T. & Rothengatter, T. (2001) Maintaining task set under fatigue: a study of time-on-task effects in simulated driving. *Transportation Research Part F*, 4 (2), pp. 103-118.

Isnainiyah, I.N., Samopa, F., Suryotrisongko, H. and Riksakomara, E. (2015). Analysis of sleep deprivation effect to driving performance using reaction test simulation. *Jurnal Teknologi*, 72(4), pp. 61-66.

Jagannath, M & Balasubramanian, V. (2014) Assessment of early onset of driver fatigue using multimodal fatigue measures in a static simulator. *Applied Ergonomics*, 45, pp. 1140-1147.

Jettinghoff, K., Houtman, I.L.D., & Evers, M. (2003) Oorzaken van vermoeidheid bij vrachtwagenchauffeurs in het beroepsgoederenvervoer. TNO-rapport 10276. TNO Arbeid, Netherlands, Hoofddorp.

Jettinghoff, K., Starren, A., Houtman, I. & Henstra, D. (2005) I love uitgerust achter het stuur!? Vermoeidheid in het verkeer: maatregelen in het buitenland en hun toepasbaarheid in Nederland. Twijnstra en Gudde, Amersfoort Accessed 7 February 2008:<http://www.rws-avv.nl/pls/portal30/docs/14655.PDF>.

Johns, M.W. (2000) A sleep physiologist's view of drowsy driving. *Transportation Research Part F*, 3, pp. 241-249.

Jones, C.B., Dorrian, J., Rajartnam, S.M.W. & Dawson, D. (2005) Working hours regulations and fatigue in transportation: a comparative analysis. *Safety Science*, 43, pp. 225-252.

Karrer, K., Briest, S., Vöhringer-Kuhnt, T., Baumgarten, T. & Schleir, R. (2005) Driving Without Awareness. In: Underwood, G. (Ed.) *Traffic & Transport Psychology; Theory and Application*, pp. 455-469. Elsevier, London.

Karrer-Gauss, K. & Zawistowski, P. (2013) Driver Fatigue Systems - How Do They Change the Drivers' Behaviour? In L. Dorn & M. Sullman (Eds.): *Driver Behaviour and Training, Volume VI* (pp. 179-186). Ashgate, UK.

Klauer, S., Dingus, T., Neale, V., Sudweeks, J., & Ramsey, D. (2006a) The Impact of Driver Inattention on Near-Crash/Crash Risk: An Analysis Using the 100-Car Naturalistic Driving Study Data (NHTSA Report No. DOT HS 810 594). Virginia Tech Transportation Institute, Blacksburg, Virginia.

Klauer, S., Sudweeks, J., Hickman, J. & Neale, V. (2006b) How risky is it? An Assessment of the Relative Risk of Engaging in Potentially Unsafe Driving Behaviors. AAA Foundation for Traffic Safety, Washington.

Klauer, S.G., Neale, V.L., Dingus, T.A., Sudweeks, J.D., & Ramsey, D.J. (2005) The Prevalence of Driver Fatigue in an Urban Driving Environment: Results from the 100-Car Naturalistic Driving Study. *Proceedings of the 2005 International Conference on Fatigue Management in Transportation Operations, September 2005 (TP 14620E)* Accessed 4 February 2008: <http://www.tc.gc.ca/tdc/publication/tp14620/papers/d11.pdf>.

Klauer, S.G., Dingus, T.A., Neale, V.L., & Carroll, R.J. (2003) The effects of fatigue on driver performance for single and team long-haul truck drivers. *Proceedings of Driving Assessment 2003 - The Second International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*. Park City, Utah Accessed 29 January 2008: http://ppc.uiowa.edu/driving-assessment/2003/Summaries/Downloads/Final_Papers/PDF/31_Klauerformat.pdf.

Krieger, J. (2007) Sleep apnoea and driving: how can this be dealt with? *European Respiratory Review*, 16, pp. 189-195.

Lal, S.K.L. & Craig, A. (2001) A critical review of the psychophysiology of driver fatigue. *Biological Psychology*, 55, pp. 173-194.

- Landolt, H.-P., Roth, C., Dijk, D.J., & Borbely, A.A. (1996) Late-afternoon ethanol intake affects nocturnal sleep and the sleep EEG in middle-aged men. *Journal of Clinical Psychopharmacology*, 16(6), pp. 428-436.
- Langwieder, K. & Sporner, A. (1994) Struktur der Unfälle mit Getöteten auf Autobahnen im Freistaat Bayern im Jahr 1991, HUK-Verband, Büro für KfZ-Technik, Munich.
- Lin, C.T., Wu, R.C., Jung, T.P., Liang, S.F., Huang, T.Y. (2005) Estimating Driving Performance Based on EEG Spectrum Analysis *EURASIP Journal on Applied Signal Processing* 2005:19, 3165-3174.
- Liu, C.C., Hosking, S.G., & Lenné, M.G. (2009) Predicting driver drowsiness using vehicle measures: Recent insights and future challenges. *Journal of Safety Research*, 40, pp. 239– 245.
- Lyznicki, J M., Doege, T C., Davis, R M., & Williams, M A. (1998) Sleepiness, driving, and motor vehicle crashes. *Journal of the American Medical Association*, 279(23), pp. 1908- 1913.
- Macchi, M.M., Boulos, Z., Ranney, T., Simmons, L., & Campbell, S.S. (2002) Effects of an afternoon nap on nighttime alertness and performance in long-haul drivers. *Accident Analysis and Prevention*, 34, pp. 825-834.
- Mackie, H.W. & Baas, P.H. (2007) The cost effectiveness of delineation improvement for safety. *Land Transport New Zealand Research Report 322*, New Zealand Accessed 29 January 2008: <http://www.ltsa.govt.nz/research/reports/322.pdf>.
- Mackie, R.R. & Miller, J.C. (1978) Effects of hours of service, regularity of schedules and cargo loading on truck and bus driver fatigue. DOT-HS-5-01142, Human Factors Research Inc.
- Massala, G.L. & Grosso, E. (2014). Real time detection of driver attention: Emerging solutions on robust iconic classifiers and dictionary of poses. *Transportation Research Part C*, 49, pp. 32-42.
- Matthews, G & Desmond, P.A. (2002) Task-induced fatigue states and simulated driving performance. *The Quarterly Journal of Experimental Psychology*, 55 (2), pp. 659-686.
- Maycock, G. (1995) Driver Sleepiness as a Factor in Car and HGV Accidents, Transport Research Laboratory (TRL), Crowthorne, Berkshire, UK.
- Maycock, G. (1996) Sleepiness and driving: the experience of UK car drivers. *Journal of Sleep Research*, 5, 220-237.
- Maycock, G. (1997) Sleepiness and driving the experience of U.K. car drivers *Accident Analysis and Prevention*, 29(4), pp 453-462.
- McCartt, A.T., Hammer, M.C., & Fuller, S.Z. (1997) Work and sleep/rest factors associated with driving while drowsy experiences among long-distance truck drivers. In *Proceedings of the 41st Annual Meeting of the Association for the Advancement of Automotive Medicine* (pp. 95–108). AAAM, Des Plaines, Illinois.

McCartt, A.T., Rohrbaugh, J.W., Hammer, M.C. & Fuller, S.Z. (2000) Factors associated with falling asleep at the wheel among long distance truck drivers. *Accident Analysis and Prevention*, 32, pp. 493-504.

McKernon, S. (2009) A literature review on driver fatigue among drivers in the general public. Research Report 342. NZ Transport Agency, Wellington.

Meuleners, L., Fraser, M.L., Govorko, M.H., Stevenson, M.R.. (2015) Obstructive sleep apnea, health-related factors, and long distance heavy vehicle crashes in Western australia: a case control study. *Journal of Clinical Sleep Medicine*, 11(4), pp. 413-418.

Meng, F., Li, S., Cao, L. Li, M., Peng, Q., Wang, C. & Zhang, W. (2015) Driving Fatigue in Professional Drivers: A Survey of Truck and Taxi Drivers, *Traffic Injury Prevention*, 16(5), pp. 474-483.

Milanovic, M. & Klemenjak, W. (1999) Psychologische Massnahmen gegen ermüdungsbedingte Unfälle bei Fernfahrern. Institut für Verkehrspsychologie, Vienna.

Miller, J.C., & Mackie, R.R. (1980) Effects of irregular schedules and physical work on commercial driver fatigue and performance. In: D.J. Osborne and J. A. Levis (eds.), *Human Factors in Transport Research*, Vol. 1. Academic Press, New York.

Mitler, M. M., Miller, J. C., Lipsitz, J. J., Walsh, J. K. & Wylie, C. D. (1997) The sleep of long-haul truck drivers. *The New England Journal of Medicine*, 337, 755-761.

Morris, D.M., Pilcher, J.J. & Switzer III, F.S. (2015). Lane heading difference: An innovative model for drowsy driving detection using retrospective analysis around curves. *Accident Analysis and Prevention*, 80, pp. 117-124.

National Transportation Safety Board (1995) Safety study: factors that affect fatigue in heavy truck accidents. NTSB Report No. SS - 95/01; NTIS No.: PB95-917001. National Transportation Safety Board, Washington, DC.

NCSCR/NHTSA Expert panel on driver fatigue and sleepiness (2001) Drowsy driving and automobile crashes http://www.nhtsa.dot.gov/people/injury/drowsy_driving1/drowsy.html.

NHTSA (2001) Drowsy driving and automobile crashes. Report of the NCSDR/NHTSA expert panel on driver fatigue and sleepiness. National Highway Traffic Safety Administration, Washington DC. http://www.nhtsa.dot.gov/people/injury/drowsy_driving1/Drowsy.html.

Nishino S, & Kanbayashi, T. (2005) Symptomatic narcolepsy, cataplexy and hypersomnia, and their implications in the hypothalamic hypocretin/orexin system. *Sleep Medicine Reviews*, 9, pp. 269-310.

Nordbakke, S & Sagberg, F. (2007) Sleepy at the wheel: Knowledge, symptoms and behaviour among car drivers. *Transport Research Part F*, 10, pp. 1-10.

Nordbakke, S. & Sageberg, F. (2007) Sleepy at the wheel: knowledge, symptoms and behaviour among car drivers. *Transportation Research Part F*, 10, pp 1-10.

O'Hanlon, J. F., & Kelley, G. R. (1977) Comparison of performance and physiological changes between drivers who perform well and poorly during prolonged vehicular operation. In R. R. Mackie (Ed.), *Vigilance: theory, operational performance and physiological correlates* (pp. 87–109). Plenum Press, New York.

Oron-Gilad, T., & Shinar, D. (2000) Driver fatigue among military truck drivers. *Transportation Research Part F: Traffic Psychology and Behaviour*, 3 (4), 195-209.

Otmani, S., Rogé, J. & Muzet, A. (2005) Sleepiness in professional drivers: Effect of age and time of day. *Accident Analysis and Prevention*, 37, pp. 930-937.

Ouwerkerk, F. van, Hoeven, W. van der, O'Hanlon, J.F. & Onnen, M. (1986) *Arbeidsomstandigheden van internationale vrachtwagenchauffeurs. Rapport VK-86-04*. Traffic Research Centre, Netherlands, Haren.

Ouwerkerk, F. van (1987) *Relationships between road transport working conditions, fatigue, health and traffic safety. Report VK 87-01*. Traffic Research centre, Netherlands, Haren.

Pack, A.I., Pack, A.M., Rodgman, E., Cucchiara, A. Dinges, D.F., & Schwab, C.W. (1995) Characteristics of crashes attributed to the driver having fallen asleep. *Accident Analysis and Prevention*, 27(6), pp. 769-775.

Peters, T., Grüner, C., Durst, W., Hütter, C., & Wilhelm, B. (2014) Sleepiness in professional truck drivers measured with an objective alertness test during routine traffic controls. *International Archives of Occupational & Environmental Health*; Nov2014, Vol. 87 Issue 8, p881

Philip, P. (2004) Sleepiness of Occupational Drivers. *Industrial Health*, 43, pp. 30-33. Philip, P., Sagaspe, P., Moore, N., Taillard, J. Charles, A., Guilleminault, C. & Bioulac, B.(2005) Fatigue, sleep restriction and driving performance. *Accident Analysis and Prevention*, 37, pp. 473-478.

Philip, P., Vervialle, F., Le Breton, P., Taillard, J. & Horne, J.A. (2001) Fatigue, alcohol, and serious road crashes in France: factorial study of national data. *British Medical Journal*, 322, pp. 829-830.

Pizza, F., Contardi, S., Antognini, A.B., Zagoraïou, M., Borrotti, M., Mostacci, B., Mondini, S., & Cirignotta F. (2010) Sleep Quality and Motor Vehicle Crashes in Adolescents. *Journal of Clinical Sleep Medicine*, 6, pp.41-45.

Radun, I. & Radun, J.E. (2009) Convicted of fatigued driving: Who, why and how? *Accident Analysis and Prevention*, 41, pp. 869-875.

Reyner, L.A. & Horne, J.A. (1998) Falling asleep whilst driving: are drivers aware of prior sleepiness? *International Journal Legal Medicine*, 111(3), pp. 120-123.

Richardson, J., Fairclough, S. H. & Fletcher, S. (1997) Driver Fatigue: An Experimental Investigation. In: Noy, Y. I. (Ed.), *Ergonomics and Safety of Intelligent Driver Interfaces*, 329-343. Erlbaum, Mahwah.

- Riemersma, J. B. J., Sanders, A. F., Wildervanck, C., & Gaillard, A. W. (1977) Performance decrement during prolonged night driving. In: Mackie, R. R. (Eds). *Vigilance Theory, Operational Performance, and Physiological Correlates*, pp 41-58, Plenum Press, New York.
- Rogé, J., Pébayle, T., Hannachi, S.El., Muzet, A.(2003) Effect of sleep deprivation and driving duration on the useful visual field in younger and older subjects during simulator driving. *Vision Research* 43, 1465-1472.
- Ronen, A., Oron-Gilad, T., Gershon, P. (2014) The combination of short rest and energy drink consumption as fatigue countermeasures during a prolonged drive of professional truck drivers. *Journal of Safety Research*, 49, pp. 39-43.
- Rosso, G.L., Perotto, M., Feola, M., Caramella, M. (2014). Falling asleep at the wheel among Italian professional drivers (PDs): Results from the HiRis PD study. *International Journal of Medicine and Environmental Health*, 27, pp. 1005-1012.
- ROSPA (2001) Driver fatigue and road accidents. A literature review and position paper. Royal Society for the Prevention of Accidents, Birmingham Accessed 15 January 2008: <http://www.rospa.com/roadsafety/info/fatigue.pdf>.
- RSA (2008) European Union Rules on Drivers' Hours. Road Safety Authority RSA, Galway.
- Sagberg, F. (1998) Many drivers fall asleep at the wheel. Institute of Transport Economics, No. 3, p. 16. *Nordic Road and Transport Research*, Norway.
- Sagberg, F. (1999) Road accidents caused by falling asleep. *Accident Analysis and Prevention*, 31, pp. 639-649.
- Sagberg, F., Jackson, P., Krüger, H.-P., Muzet, A. & Williams, A. (2004) Fatigue, sleepiness and reduced alertness as risk factors in driving. TØI report 739/2004. TØI, Oslo.
- Sassani, A., Findley, L.J., Kryger, M., Goldlust, E., George, C. & Davison, T.M. (2004) Reducing motor-vehicle collisions, costs, and fatalities by treating obstructive sleep apnea syndrome. *Sleep*, 27, pp. 453-458.
- Schagen, I.N.L.G.van (2003) Vermoeidheid achter het stuur. Report 2003-16, Institute for Road Safety Research SWOV, Netherlands, Leidschendam Accessed 15 January 2008: <http://www.swov.nl/rapport/R-2003-16.pdf>.
- Sleep Medicine 23, pp. 383-389 Sleepiness in highway vehicle accidents. *Sleep*, 24, pp.203-206.
- Stutts, J. C., Wilkins, J.W., Osberg, J. S. Vaughn, B.V. (2003) Driver risk factors for sleep-related crashes. *Accident Analysis and Prevention*, 35(3), 321-331.
- Stutts, J.C., Wilkins, J.W. & Vaugh, B.V. (1999) Why do people have drowsy driving crashes? Input from drivers who just did. AAA Foundation for Traffic Safety, Washington DC Accessed 4 February 2008: <http://www.aaafoundation.org/pdf/Sleep.pdf>
Summary. Publication No. FMCSA-RRA-07-017. Federal Motor Carrier Safety.

Sun, Y. and YU, X. (2013) An Innovative Non-intrusive Driver Assistance System for Vital Signal Monitoring. IEEE, Journal of Biomedical and Health Informatics, Vol. 18, No. 6, pp. 1932 – 1939.

Terán-Santos, J., Jiménez-Gómez, A., Cordero-Guevara, J. & the cooperative Group Burgos-Santander (1999) The association between sleep apnea and the risk of traffic accidents. In: New England Journal of Medicine, 340(11), pp. 847-851.

Tasmanian Government (2015). A guide to heavy vehicle reform in Tasmania and how it affects you. Tasmanian Department of Infrastructure, Energy and Resources (DIER), Tasmania.

Tasmanian Government (2015). Newsletter 5, 5 March 2015. National heavy vehicle fatigue law. Chain of responsibility Department of State Growth.

Thompson, J. & Stevenson, M. (2014) Associations between heavy-vehicle driver compensation methods, fatigue-related driving behaviour, and sleepiness. Traffic Injury Prevention, 15, pp. S10-S14.

Thiffault, P. & Bergeron, J. (2003) Fatigue and individual differences in monotonoussimulated driving. Personality and Individual Differences, 34 (1), pp. 159-179.

Ting, P.-H., Hwant, J.-R., Doong, J.-L. & Jeng, M.-C. (2008). Driver fatigue and highway Transportation Institute, Blacksburg, Virginia.

Torregroza-Vargas, N.M., Bocarejo, J.P., & Ramos-Bonilla, J.P. (2014) Fatigue and crashes: The case of freight transport in Colombia. Accident Analysis and Prevention, 72, pp. 440-448.

Vanlaar, W., Simpson, H., Mayhew, D. & Robertson, R. (2007) Fatigued and Drowsy Driving. Attitudes, Concern and Practices of Ontario Drivers. Traffic Injury Research Foundation, Ontario http://www.trafficinjuryresearch.com/publications/PDF_publications/Fatigued_and_Drowsy_Driving_in_Ontario.pdf.

Vanlaar, W., Simpson, H., Mayhew, D., & Robertson, R. (2008) Fatigued and drowsy driving: A survey of attitudes, opinions and behaviors. In: Journal of Safety Research, vol. 39, pp. 303-309.

Verwey, W. B. & Zaidel, D. M. (2000) Predicting drowsiness accidents from personal attributes, eye blinks and ongoing driving behaviour. Personality and Individual Differences, 28 (1), pp. 123-142.

Vincent, A., Noy, I. & Laing, A. (1998) Behavioural adaptation to fatigue warning systems. Transport Canada. Canada. Paper Number 98-S2-P-2 1. Proceedings of the 16th International Technical Conference on the Enhanced Safety of Vehicles, Windsor, Canada Accessed 4 February 2008: <http://www-nrd.nhtsa.dot.gov/pdf/nrd-01/Esv/esv16/98S2P21.PDF>.

VOSA (2009) Rules on Drivers' Hours and Tachographs Goods vehicles in the UK and Europe. Revised 2009 GV262 – 02. Vehicle & Operator Services Agency VOSA, Bristol.

Wang, L. & Pei, Y. (2014) The impact of continuous driving time and rest time on commercial drivers' driving performance and recovery. *Journal of Safety Research*, 50, pp. 11-15.

WB & A Market Research (2002) 2002 "Sleep in America" Poll. National Sleep Foundation, Washington D.C. Accessed 13 February 2008: <http://www.kintera.org/atf/cf/{F6BF2668-A1B4-4FE8-8D1A-A5D39340D9CB}/2002SleepInAmericaPoll.pdf>.

Wierwille, W. W. & Ellsworth, L. A. (1994) Evaluation of driver fatigue by trained raters. *Accident Analysis and Prevention*, 26(4), pp. 571-578.

Williamson, A. & Chamberlain, T. (2005) Review of on-road driver fatigue monitoring devices. Technical Report, NSW Injury Risk Management Research Centre, University of New South Wales

Williamson, A., & Feyer, A-M. (2000) Moderate sleep deprivation produces impairments in cognitive and motor performance equivalent to legally prescribed levels of alcohol intoxication. *Journal of Occupational and Environmental Medicine*, 57, pp. 649-55.

Williamson, A., Lombardi, D.A., Folkard, S., Stutts, J., Courtney, T.K. & Connor, J. L. (2011) The link between fatigue and safety. *Accident Analysis and Prevention*, 43, pp 498-515.

Williamson, A.M. & Feyer, A-M. (2000) Moderate sleep deprivation produces comprehensive cognitive and motor performance impairments equivalent to legally prescribed levels of alcohol intoxication. *Occupational and Environmental Medicine*, 57, pp. 649-655.

Williamson, A., Friswell, R., Olivier, J. & Grzebieta (2014) Are drivers aware of sleepiness and increasing crash risk while driving. *Accident Analysis and Prevention*, 70, pp. 225-234.

Winsum, W. van (1999). Age-related differences in effects of drowsiness on measures of driver behaviour and performance. Rapport TM-99-C001. TNO Technische Menskunde, Netherlands, Soesterberg.

Wright, N.A., Stone, B.M., Horberry, T.J., & Reed, N. (2007) A review of in-vehicle sleepiness detection devices. Published project Report 157. TRL Limited, UK, Crowthorne Accessed 29 January 2008: http://www.trl.co.uk/store/report_detail.asp?srid=6171&pid=211.

Wylie, C.D., Shultz, T., Miler, J.C., Mitler, M.M., & Mackie, R.R. (1996) Commercial Motor Vehicle Driver Fatigue and Alertness Study. Technical Summary. FHWA report FHWA-MC- 97-001. FHA, Washington DC Accessed 12 February 2008: <http://www.fmcsa.dot.gov/facts-research/research-technology/publications/cmvmfatiguestudy.htm>.

Yang, J.H., Mao, Z-H., Tijerina, L., Pilutti, T., Coughlin, J.F. & Feron, E. (2009) Detection of Driver Fatigue Caused by Sleep Deprivation. *IEEE Transaction on Systems, Man, and Cybernetics — Part A: Systems and Humans*, Vol. 39, No. 4, pp. 694-705.

Yee, B., Campbell, A., Beasley, R., & Neill, A. (2002) Sleep disorders: a potential role in New Zealand motor vehicle accidents. *Intern Med Journal*, 32, pp. 297-304.

Notes

1. Country abbreviations

	Belgium	BE		Italy	IT		Romania	RO
	Bulgaria	BG		Cyprus	CY		Slovenia	SI
	Czech Republic	CZ		Latvia	LV		Slovakia	SK
	Denmark	DK		Lithuania	LT		Finland	FI
	Germany	DE		Luxembourg	LU		Sweden	SE
	Estonia	EE		Hungary	HU		United Kingdom	UK
	Ireland	IE		Malta	MT			
	Greece	EL		Netherlands	NL		Iceland	IS
	Spain	ES		Austria	AT		Liechtenstein	LI
	France	FR		Poland	PL		Norway	NO
	Croatia	HR		Portugal	PT		Switzerland	CH

2. This 2018 edition of Traffic Safety Synthesis on Fatigue updates the previous versions produced within the EU co-funded research projects [SafetyNet](#) (2008) and [DaCoTA](#) (2012). This Synthesis on Fatigue was originally written in 2008 and then updated in 2012 and in 2015 by Charles Goldenbeld, [SWOV](#).

3. All Traffic Safety Syntheses of the European Road Safety Observatory have been peer reviewed by the Scientific Editorial Board composed by: George Yannis, NTUA (chair), Robert Bauer, KFV, Christophe Nicodème, ERF, Klaus Machata, KFV, Eleonora Papadimitriou, NTUA, Pete Thomas, Un.Loughborough.

4. Disclaimer

This report has been produced by the National Technical University of Athens ([NTUA](#)), the Austrian Road Safety Board ([KFV](#)) and the European Union Road Federation ([ERF](#)) under a contract with the [European Commission](#). Whilst every effort has been made to ensure that the matter presented in this report is relevant, accurate and up-to-date, the Partners cannot accept any liability for any error or omission, or reliance on part or all of the content in another context.

Any information and views set out in this report are those of the author(s) and do not necessarily reflect the official opinion of the Commission. The Commission does not guarantee the accuracy of the data included in this study. Neither the Commission nor any person acting on the Commission's behalf may be held responsible for the use that may be made of the information contained therein.

5. Please refer to this Report as follows:

European Commission, Fatigue, European Commission, Directorate General for Transport, February 2018.

