Institute of Transport Economics

Fatigue, sleepiness and reduced alertness as risk factors in driving

Fridulv Sagberg
Paul Jackson
Hans-Peter Krüger
Alain Muzet
Adrian Williams

TØI report 739/2004

TØI report

739/2004

Fatigue, sleepiness and reduced alertness as risk factors in driving

Fridulv Sagberg, Paul Jackson, Hans-Peter Krüger, Alain Muzet, Adrian Williams

ISSN 0802-0175

ISBN 82-480-0450-3

Oslo, December 2004

Title: Fatigue, sleepiness and reduced alertness as risk factors in driving

Author(s): *Fridulv Sagberg; Paul Jackson; Hans-Peter Krüger; Alain Muzet; Adrian Williams*

TØI report 739/2004
Oslo, 2004-12
54 pages
ISBN 82-480-0450-3
ISSN 0802-0175

Financed by:
European Commission

Project: 2718 IMMORTAL

Project Fridulv Sagberg

Quality manager: Nicholas J. Ward

Key words:
Fatigue; Sleep; Driver behaviour; Traffic safety; Sleep-related road accidents

Summary:
The report is based on presentations at a workshop about driver fatigue and sleepiness, organised by TØI as part of the EU project IMMORTAL in September, 2003. The following topics are presented and discussed: 1) Incidence of driver sleep, and the role of sleep and fatigue in crashes. 2) The biological basis of sleep, and medical and clinical aspects. 3) Simulator studies of fatigue indicators. 4) Eye and eyelid movements as fatigue indicators. 5) In-car warning systems to prevent falling asleep while driving. 6) Fatigue management among occupational drivers.

Tittel: Trøtthet, sovning og redusert årvåkenhet som risikofaktorer ved bilkjøring.

Forfatter(*Fridulv Sagberg; Paul Jackson; Hans-Peter Krüger; Alain Muzet; Adrian*

TØI rapport 739/2004
Oslo: 2004-12
54 sider
ISBN 82-480-0450-3
ISSN 0802-0175

Finansieringskilde:
EU-kommisjonen

Prosjekt: 2718 IMMORTAL

Prosjektleder: Fridulv Sagberg

Kvalitetsansvarli Nicholas J. Ward

Emneord:
Trøtthet; Søvn; Bilføreratferd; Trafikksikkerhet; Søvnrelaterte trafikkulykker

Sammendrag:
Rapporten er basert på presentasjoner fra en workshop om trøtthet og bilkjøring som TØI arrangerte innenfor EU-prosjektet IMMORTAL i september 2003. Temaene som presenteres og diskuteres omfatter: 1) Omfang av trøtthet og sovning blant bilførere, og ulykker som følge av dette. 2) Det biologiske grunnlaget for søvn, samt medisinske og kliniske aspekter. 3) Simulatorstudier av indikatorer på trøtthet. 4) Bevegelser av øyne og øyelokk som indikatorer på trøtthet under kjøring. 5) Varslingssystemer i bilen for å motvirke kjøring i trøtt tilstand. 6) tiltak mot trøtthet blant yrkesførere.

Language of report: English

The report can be ordered from:
Institute of Transport Economics,
P O Box 6110 Etterstad N-0602 Oslo,
Telephone +47 22 57 38 00 Telefax +47 22 57 02 90
Price NOK 200

Rapporten kan bestilles fra:
Transportøkonomisk institutt, biblioteket
Postboks 6110 Etterstad, 0602 Oslo
Telefon 22 57 38 00 - Telefaks 22 57 02 90
Pris 200

Copyright © Transportøkonomisk Institutt 2004
Denne publikasjonen er vernet i henhold til Åndsverkloven av
Ved gjengivelse av materiale fra publikasjonen, må fullstendig kilde oppgis

*

Preface

Drivers who fall asleep at the wheel, or who have reduced alertness due to fatigue, represent a considerable road safety problem, which has received broad attention from authorities, media, the general public, as well as from the research community during the recent years. This topic is included also in the EU project IMMORTAL (2002 – 2005), together with various other temporary or chronic driver impairments. The Institute of Transport Economics (TØI) participates in several activities within IMMORTAL, and in September 2003 the institute was responsible for organising a workshop about driver fatigue. This report is based on the presentations in the workshop.

Presentations from the following invited speakers are included in the report:
Dr. Adrian J. Williams, St. Thomas Hospital, London (Chapter 3).
Dr. Alain Muzet, CNRS-CEPA, Strasbourg (Chapters 4 and 6).
Dr. Hans-Peter Krüger, Universitetet i Würzburg (Chapter 5).
Dr. Paul Jackson, Awake Ltd., London (Chapter 7).

Fridulv Sagberg, TØI, has edited the contributions and written the remainder of the report. Trude Rømming has prepared the report for printing.

Oslo, December 2004
Institute of Transport Economics

Sønneve Ølnes
Acting Managing Director

Marika Kolbenstvedt
Head of Department

TABLE OF CONTENTS

Authors: Fridulv Sagberg, Paul Jackson, Hans-Peter Krüger, Alain Muzet, Adrian Williams
Oslo 2004, 54 pages English language

Executive summary:

Fatigue, sleepiness and reduced alertness as risk factors in driving

The present report summarises presentations and discussions from a workshop entitled "Fatigue, sleepiness, and reduced alertness as risk factors in driving". The workshop was a part of the EU project IMMORTAL.

Driver fatigue or falling asleep is recognized to be among the most important causative factors in road crashes, next to alcohol, speeding and inattention. (Certainly fatigue-related hypovigilance is related to inattention, but for practical purposes it may be useful to distinguish fatigue and sleepiness from other factors leading to inattention.) The purpose of the IMMORTAL project is to assess both chronic and acute driver impairments, and fatigue and drowsiness belong primarily among the acute impairments, although chronic impairment is also involved, as far as sleep disorders are concerned. Some of the issues discussed in the IMMORTAL workshop on fatigue were:

- The scope of the problem
- Normal and clinical aspects of excessive daytime sleepiness
- Detection of drowsiness in drivers – experiences from simulated driving
- Early signs of falling asleep while driving
- Efficiency of countermeasures to be used by drivers
- Driver alertness monitoring and warning systems
- Drivers with sleep disorders, and implications for licensing procedures

There are basically two types of data from drivers that are relevant as indicators of the scope of the problem. The first concerns the prevalence of sleepiness among drivers, and the incidence of actually falling asleep. The prevalence of fatigue without actually falling asleep is extremely difficult to assess, and no good estimates can be found. Concerning drivers who have actually fallen asleep, the estimates for a 12-month period range from 8 to 29 % of drivers. A rather conservative estimate then is that about one in ten drivers fall asleep at least once in a year. Barring the possibility of multiple occurrences for each driver, this implies an incidence of about one such event per 100 000 km.

The report can be ordered from:
Institute of Transport Economics, PO Box 6110 Etterstad, N-0602 Oslo, Norway
Telephone: +47 22 57 38 00   Telefax: +47 22 57 02 90

The second type of data relates directly to the role of fatigue and falling asleep as primary or contributing cause of accidents. Among those who report that they have fallen asleep, between 4 and 14 % (differing between studies) report that the incident resulted in a crash.

It has been estimated that between 7 and 30 % of all personal injury crashes are caused by fatigue or sleep. And the evidence is clear that sleep- and fatigue-related crashes are on the average more severe than other crashes.

The risk of sleep-related crashes seems to vary with time of day, mirroring roughly the biologically based circadian variations in sleepiness and vigilance. This means that the risk shows a peak late at night or early in the morning, and a smaller peak in the afternoon. Although the *risk* of sleep and fatigue related crashes is larger during the night than during the day, the *absolute number* of such crashes is as high during the day as during the night, due to the larger exposure during daytime. Countermeasures should therefore address the problem of falling asleep during daytime as well as during the night.

The risk also tends to increase with prolonged driving, and the research evidence seems to give some support for current regulations of rest breaks during the drive as well as for total daily driving hours for professional drivers. More research is however needed to establish the optimal rest-work schedules.

Excessive sleepiness seems to be a widespread problem lying at the base of sleep- and fatigue-related crashes. This is primarily caused by “too much wakefulness”, as well as the circadian rhythm of sleepiness. In addition to those influences on daytime sleepiness, which everyone is subject to, some drivers are excessively sleepy because of some sleep disorder. The most prevalent sleep disorder is the obstructive sleep apnoea syndrome, which is a result of stopped breathing during sleep, resulting in poor quality of sleep and consequently excessive daytime sleepiness. This disorder affects as many as 4-5% of middle-aged men, who are the group with the highest prevalence. And then there is narcolepsy, or “intrinsic sleepiness”; patients with this condition are prone to fall asleep at any time. The prevalence is about 1 in 2000, and this group is clearly over-involved in crashes.

Sleep disorders clearly have potential implications for licensing procedures. However, current methods are to a large extent dependent upon self-report instruments. This means that only individuals that present a sleep-related complaint to their doctor will be assessed with respect to implications for driving. And as long as the licensing requirements in several countries leave to the patients themselves to consider their suitability for driving in relation to sleepiness, there is no guarantee that even people with sleep disorders actually will refrain from driving. There are also objective methods for assessing sleepiness and the preconditions for falling asleep. By the use of such methods, important knowledge has

Copyright © Institute of Transport Economics, 2004

been obtained regarding early signs, which may indicate a danger of falling asleep. Such knowledge can be used for information to drivers to pay attention to those signs, and stop driving when they occur.

There is a growing body of research on technical devices to record the drivers' vigilance states as well as their driving behaviour, with the purpose of giving a warning and/or interfere with the driving when the state of the driver is not compatible with the requirements from the traffic environment. An important future research need is field trials of such systems in order to assess their effect on driver behaviour and crash risk.

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 to much on the safety system. Further research is needed to investigate how drivers adapt their driving to such systems, and what operational precautions should be taken to avoid risky behavioural adaptation.

Drivers are often not motivated to take a break and have a nap when becoming fatigued or tired, but rather tend to engage in several activities in order to keep awake. Research has shown that most such activities (opening the window, increasing the volume of the radio, etc.) at best can postpone sleep for only a few minutes. The only effective countermeasure against sleepiness is sleep, preferably combined with a caffeine drink. A nap of at least 15 minutes is very effective and enables a driver to continue driving in an alert and vigilant condition for a considerable period. The nap should not exceed 30 minutes, because longer sleep may produce sleep inertia, from which the driver needs a certain time to recover.

It is important to increase drivers' awareness of the risks associated with driving when fatigued or sleepy, and about the effects of various countermeasures. The management of companies employing drivers have a special responsibility to take care that their employees are rested and fit and sufficiently aware of the risks, and also that their working schedules (especially for shift-workers) are compatible with the needs for rest and sleep. Educational programmes have been developed for helping both companies and individuals to manage fatigue in an adequate way. Concerning warning systems an important message should be that these systems do not reduce sleepiness, but they are only backup systems in case the driver is not sufficiently aware of the fatigue symptoms. Safe use as well as adequate training and information regarding new technical systems is part of the joint responsibility of employers and employees under the Occupational Safety and Health legislation regarding duty of care for a safe working place, including the vehicles used in employment.

Copyright © Institute of Transport Economics, 2004

It has been assumed that a monotonous road and vehicle environment may facilitate sleepiness. It is, however, somewhat controversial whether this can occur in rested drivers. It may be that monotony and boredom *permit* sleep in a driver who has insufficient sleep, but that it does not *cause* sleepiness. Some preliminary simulator studies of night driving have shown that road lighting has little effect on the development of sleepiness in general, but further research is needed on this issue, to find out to what extent environmental measures can contribute to the prevention of fatigue-related accidents. The idea that monotony and boredom permit sleep also implies on the other hand that stimulation may *mask* sleepiness. Even if one is very sleepy it is not difficult to stay awake while walking around, but once seated comfortably in the car one may fall asleep very quickly.

Countermeasures against fatigue and sleep-related accidents are of two types. They can either prevent drivers from falling asleep or developing fatigue while driving, or they can alert a driver or intervene with driving once a driver's performance is impaired. Thus, there is both primary and secondary prevention of such accidents. Examples of primary prevention are information to raise driver's awareness of early signs of fatigue or sleepiness, or warning systems detecting such signs. For professional drivers an additional countermeasure is the hours-of-service regulations. Rumble lines along the edge or centre of the road (profiled edgelines/centrelines) is an example of a secondary prevention that has proven very effective. Other examples are the in-car systems to wake up a driver who has fallen asleep.

Copyright © Institute of Transport Economics, 2004

TØI-rapport 739/2004
Forfattere: Fridulv Sagberg, Paul Jackson, Hans-Peter Krüger, Alain Muzet, Adrian Williams
Oslo 2004, 54 sider

Sammendrag:

Trøtthet, sovning og redusert årvåkenhet som risikofaktorer ved bilkjøring

Denne rapporten sammenfatter presentasjoner og diskusjoner fra en workshop med tittelen ”Fatigue, sleepiness, and reduced alertness as risk factors in driving”. Workshopen var en del av EU-prosjektet IMMORTAL.

Trøtthet og sovning anses å være blant de viktigste årsakene til trafikkulykker, i tillegg til alkohol, fart og uoppmerksomhet. (Redusert årvåkenhet forbundet med trøtthet kan riktignok sies å være en form for uoppmerksomhet, men for praktiske formål kan det være hensiktsmessig å skille mellom trøtthet og andre forhold som fører til uoppmerksomhet.) Formålet med IMMORTAL-prosjektet er å kartlegge ulykkesrisiko forbundet med både kroniske og akutte svekkelser blant bilførere. Trøtthet og sovning er primært å regne som akutte svekkelser, men det er også noen tilfeller som er av mer kronisk karakter, slik som søvnrelaterte sykdommer.

Temaene som ble presentert og diskutert i workshopen omfattet blant annet:

- Omfang av problemet
- Fysiologiske og kliniske aspekter ved søvn og trøtthet
- Indikatorer på trøtthet hos bilførere – erfaringer fra kjøresimulator
- Tidlige tegn (forvarsler) før en sovner under kjøring
- Effekter av tiltak for å holde seg våken
- Tekniske systemer for å advare førere mot å sovne
- Førere med søvnrelaterte sykdommer, og implikasjoner for førerkort

Det er hovedsakelig to typer data fra førere som sier noe om omfanget av problemet. Den første kategorien dreier seg om hvor ofte det forekommer at bilførere er trøtte eller faktisk sovner. Forekomst av trøtthet uten at føreren faktisk sovner er svært vanskelig å anslå, og det finnes ingen gode anslag på dette. Når det gjelder hyppighet av sovning under kjøring, er det anslått at mellom 8 og 29 % av førerne sovner i løpet av en 12-måneders periode. Et forsiktig anslag vil dermed være at minst 1 av 10 førere sovner bak rattet i løpet av et år. Ser en bort fra at noen førere kan sovne mer

enn en gang i løpet av et år, innebærer dette omtrent ett sovningstilfelle pr. 100 000 km.

Den andre kategorien data dreier seg om betydningen av trøtthet og sovning som utløsende eller medvirkende faktor i ulykker. Blant de som rapporterer at de har sovnet, svarer mellom 4 og 14 % (i ulike studier) at hendelsen resulterte i en ulykke.

Det har vært anslått at mellom 7 og 30 % av alle personskadeulykker er forårsaket av trøtthet eller sovning. Og evidensen peker klart i retning av at trøtthetsrelaterte ulykker i gjennomsnitt er alvorligere enn andre ulykker.

Risikoen for trøtthetsrelaterte ulykker ser ut til å variere med tid på døgnet og avspeiler den biologisk betingede døgnvariasjonen i trøtthet og årvåkenhet. Dette innebærer at risikoen når en topp sent på natta eller tidlig om morgenen, og det er dessuten et mindre topp om ettermiddagen. Selv om *risikoen* for trøtthetsulykker er høyere om natta enn om dagen, er det *absolutte antallet ulykker* minst like høyt om dagen som om natta, fordi trafikkarbeidet er så mye større om dagen. Mottiltak mot sovning bak rattet bør derfor rettes like mye mot kjøring om dagen som om natta.

Risikoen ser også ut til å øke jo lengre en kjører, og forskningen ser ut til å gi en viss støtte for de gjeldende kjøre- og hviletidsregler for tungbilførere når det gjelder betydningen både av kjøretid og av døgnhvil. Det er imidlertid behov for mer forskning for å kunne avgjøre hva som er de gunstigste måter å regulere kjøre- og hviletid på med tanke på sikkerheten.

Trøtthet under kjøring skyldes dels for lite søvn (”for mye våkenhet”) på forhånd, og dels kjøring på tider hvor prestasjonsnivået er redusert på grunn av den biologiske rytmen. I tillegg til disse forholdene, som gjelder alle personer, er det noen førere som lider av ulike søvnforstyrrelser. Den mest vanlige søvnsykdommen er søvn-apné (”snorkesyke”), som gir seg utslag i at pusten stopper opp i perioder under søvn. Dette gir seg utslag i redusert søvnkvalitet og følgelig økt søvnighet om dagen. Denne tilstanden berører så mange som 4-5 % av middelaldrende menn, som er den gruppen som har høyest forekomst. En annen søvnsykdom er narkolepsi, som innebærer en tendens til å sovne plutselig og uten forvarsel. Dette forekommer hos ca. 1 av 2000 personer, og denne gruppen er klart overrepresentert i trafikkulykker.

Søvnproblemer kan ha mulige implikasjoner for retten til å inneha førerkort.Et problem når det gjelder å identifisere førere med slike problemer, er at legene i stor grad er avhengig av pasientens selvrapport for å stille en diagnose som dreier seg om økt søvnighet. Dette betyr at bare pasienter som presenterer et søvnproblem for sin lege blir vurdert med tanke på rett til å kjøre bil. Og så lenge som førerkortbestemmelsene i mange land overlater til føreren selv å vurdere sin trøtthetstilstand med tanke på skikkethet for å kjøre bil, er det ingen garanti for at personer med søvnproblemer vil avstå fra å kjøre bil. Det finnes mer objektive metoder for å vurdere trøtthetsgrad og sannsynlighet for å sovne. Imidlertid brukes ikke slike metoder rutinemessig i klinisk sammenheng, men primært for forskning. Slike metoder har bl.a. gitt kunnskap om tidlige tegn som kan si

Copyright © Transportøkonomisk institutt, 2004
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

noe om risikoen for å sovne. Det er dermed mulig å gi førere informasjon om slike tidlige tegn, slik at de kan bli mer bevisst på sin trøtthetsgrad og stoppe når de merker trøtthetssymptomene.

Det er en økende mengde forskning på ulike tekniske systemer for å registrere føreres årvåkenhet og kjøreprestasjon, for å kunne varsle føreren eller stoppe bilen dersom førerens tilstand ikke er forenlig med sikker kjøring. Et viktig framtidig forskningsbehov er praktisk utprøving av slike systemer for å se i hvilken grad de påvirker kjøreatferd og ulykkesrisiko.

En mulig negativ effekt av varslingssystemer i bilen kan være at førerne benytter systemet for å kunne holde seg våken lengre i stedet for å stoppe og ta en hvil; dette vil være et eksempel på risikokompensasjon fordi en stoler for mye på det tekniske systemet. Videre forskning er nødvendig for å finne ut mer om hvordan bilførere tilpasser kjøringen til slike systemer, og hvilke tiltak som eventuelt kan settes i verk for å unngå risikoøkende atferdstilpasning.

Ofte er bilførere lite motiverte for å stoppe når de blir trøtte, siden det nødvendigvis forlenger reisetiden. I stedet prøver mange ulike tiltak for å holde seg våkne og kjøre videre til tross for trøttheten. Forskningen tyder på at de fleste av de vanligste tingene førere gjør for å holde seg våkne (åpne vinduet, sette på musikk, etc.) har liten eller ingen effekt. I beste fall kan de virke i noen minutter. Det eneste effektive tiltaket dersom en skal kjøre videre, er å ta en kort lur, eventuelt kombinert med å drikke kaffe. En lur på minst 15 minutter er svært effektivt og kan gjøre en fører i stand til å holde seg våken i flere timer. En slik lur før en kjører videre bør ikke vare lengre enn ca. 30 minutter; dersom en sover lengre vil en føle seg ”søvndrukken” og trenger tid til å komme seg av dette.

Det er viktig å bevisstgjøre bilførere om risikoen forbundet med kjøring i trøtt tilstand, og om (mangel på) virkning av ulike tiltak. Når det gjelder yrkesførere, har bedriftsledelsen et særlig ansvar for å sørge for at deres ansatte både får mulighet for tilstrekkelig hvile før og under kjøringen, og at de har tilstrekkelig kjennskap til risikofaktorene. Det er utviklet ulike opplærings- og informasjonsopplegg både for bedrifter og enkeltpersoner som dreier seg om hvordan en bør forholde seg for å unngå trøtthetsrelaterte ulykker. Når det gjelder varslingssystemer, bør et viktig budskap være at disse systemene ikke reduserer trøttheten, men at de bare skal være en ekstra sikkerhet dersom føreren selv ikke er nok bevisst på trøtthetssymptomene. Sikker bruk så vel som tilstrekkelig opplæring og informasjon om ny teknologi er del av det felles ansvar arbeidstakere og arbeidsgivere har i henhold til lovgivning om arbeidsmiljø og arbeidervern en har i de fleste land. For yrkesførere omfatter dette selvsagt også teknisk utstyr i bilene.

Det har vært antatt at både et monotont veimiljø og komfortable biler kan bidra til økt trøtthet. Det er imidlertid noe omstritt hvorvidt dette kan skje med førere som er tilstrekkelig uthvilt før kjøringen. Det kan være slik at monotoni og kjedsomhet øker sannsynligheten for at en i utgangspunktet trøtt fører sovner, men at det ikke *forårsaker* trøtthet hos en uthvilt fører. Foreløpige resultater fra simulatorstudier av nattkjøring tyder på at

Copyright © Transportøkonomisk institutt, 2004
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

veibelysning har liten effekt på trøtthet, men videre forskning er nødvendig her for å finne ut mer om i hvilken grad tiltak i veimiljøet kan bidra til å forebygge trøtthetsrelaterte ulykker. Ideen om at monotoni muliggjør trøtthet (men ikke forårsaker den) innebærer på den andre siden at stimulering kan *maskere* trøttheten. Selv om en er svært trøtt, er det liten sannsynlighet for å sovne dersom en går omkring, mens søvnen kan inntre ganske raskt så snart en setter seg i et behagelig bilsete.

Det er i hovedsak to typer tiltak for å forebygge trøtthetsrelaterte ulykker. De kan enten hindre at føreren sovner eller blir trøtt under kjøring, eller de kan varsle føreren eller gripe inn i kjøringen dersom trøttheten går ut over kjøreferdigheten. Det er altså snakk om både primær og sekundær forebygging av slike ulykker. Eksempler på primær forebygging er informasjon for å bevisstgjøre førere om tidlige varsler om fare for å sovne, eller varslingssystemer som registrerer tidlige tegn. For førere av tunge kjøretøyer er i tillegg kjøre- og hviletidsreglene et eksempel på et tiltak med sikte på primær forebygging. Profilerte kantlinjer (”rumlelinjer”) er et eksempel på sekundær forebygging som har vist seg svært effektivt. Andre eksempler er systemer i bilen som vekker en fører som har sovnet.

Copyright © Transportøkonomisk institutt, 2004
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

1. INTRODUCTION AND BACKGROUND

1.1 THE "IMMORTAL" PROJECT

The present report summarises contributions presented at a workshop entitled "Fatigue, sleepiness and reduced alertness as risk factors in driving", which was held in Oslo on September 15th, 2003. The workshop was task number P4.2 of the project IMMORTAL. IMMORTAL is a project financed by the EC under the 5th Framework Programme for RTD, with the general aim of providing knowledge about driver impairments and their implications for road safety, in order to contribute to establishing better criteria for licensing as well as methods for detecting impairments among drivers. Further information about IMMORTAL can be found on the website www.immortal.or.at.

1.2 ORGANIZATION OF THE WORKSHOP

The workshop consisted of 6 invited presentations, combined with plenary discussions. The first presentation, given by Fridulv Sagberg[1], was an introduction to the whole field, to indicate the scope of the problem, some basic facts about drivers being fatigued or falling asleep, and the relationships with crash risk, and some current issues.

The remainder of the workshop was divided into two consecutive sessions. The first session focused mainly on causes and consequences, and it contained a presentation by Dr. Adrian J. Williams[2] on normal aspects of sleepiness and its effect on performance, as well as on the clinical aspects and sleep disorders. Then Dr. Alain Muzet[3] presented his work on sleepiness precursors and indicators, as measured in a driving simulator.

The main focus of the second session was on countermeasures. First, Dr. Hans-Peter Krüger[4] presented further material on precursors, sleepiness assessment, and drivers' self-initiated countermeasures against fatigue and sleepiness. Implications of this research for driver warning systems were discussed. Then Dr. Alain Muzet presented the AWAKE project, which is a EU project with the purpose of developing a monitoring and warning system for preventing drivers from falling asleep while driving. Finally, Dr. Paul Jackson[5] presented his experiences from working with driver sleepiness and fatigue management in large companies. The full programme of the workshop is included in Appendix 1, and the list of participants in Appendix 3.

---

[1] Institute of Transport Economics, Oslo
[2] Lane-Fox Respiratory Unit & Sleep Disorder Centre, St. Thomas Hospital, London
[3] CNRS Centre National de la Recherche Scientifique – CEPA Centre d'Études de Physiologie Appliquée, Strasbourg
[4] , Interdiziplinäres Zentrum für Verkehrswissenschaften, Psychologisches Institut, Universität Würzburg
[5] Awake Ltd., London

Copyright © Institute of Transport Economics, 2004

1.3 RESPONSIBILITY FOR THE PRESENT REPORT

Chapters 1, 2, 8, 9 and 10 are authored by Fridulv Sagberg. Chapters 3 through 7 are based on the workshop presentations by Paul Jackson, Hans-Peter Krüger, Alain Muzet, and Adrian J. Williams. All chapters have been edited by Fridulv Sagberg, and some material from the workshop discussions and some references to other research have been added where this was considered relevant.

Copyright © Institute of Transport Economics, 2004

2. THE SCOPE OF THE PROBLEM

A large body of research on the effects of reduced vigilance, primarily related to fatigue or drowsiness, on the risk of road crashes has accumulated over the past couple of decades.

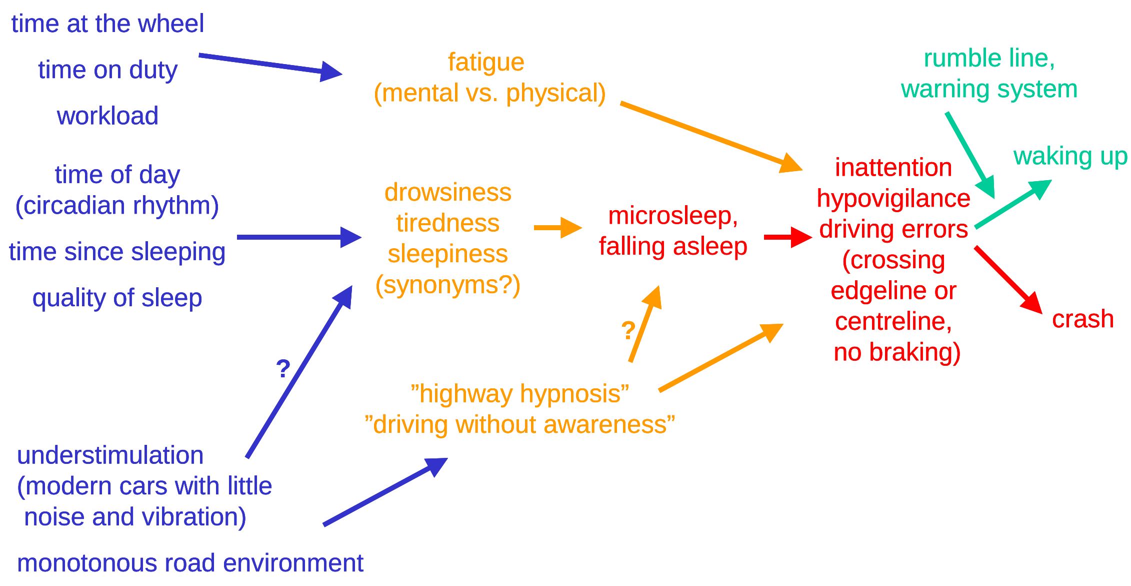
At the conceptual level, hypovigilance can be considered the end result of different states of the driver. There is a difference between being fatigued and actually falling asleep, in terms of the driver's appreciation of his own condition. Reduced vigilance due to fatigue or sleepiness may not always be easily defined and appreciated by the drivers themselves, since there is a gradual development from being fully alert and fit, through being a little tired, to feeling really fatigued or sleepy. At a certain point the state of hypovigilance is definitely detectable by the subject. However, to assess the role of this condition as a cause of a road crash is rather difficult. Therefore, such estimates are necessarily uncertain. On the other hand, if it can be ascertained that a crash-involved driver had actually fallen asleep, it is easier to conclude that there was a causal relationship between the state of falling asleep and the crash. Of course, there may be underreporting of such events, either because the driver fears legal prosecution, or because (s)he was not aware of having dozed off (there are indications that short periods of microsleep may occur without the person's appreciation of the temporary loss of awareness).

A conceptual map of some of the states, background factors and consequences of hypovigilance is shown in Figure 1.

2.1 INCIDENCE OF FALLING ASLEEP AT THE WHEEL

On this background, estimates of the prevalence of fatigued driving, as well as its role in crash causation, are uncertain. Different surveys where drivers have been asked whether they have fallen asleep at the wheel some time during their driving career, have given estimates ranging between 23 and 52 %. (Gårder and Alexander, 1995; McCartt, Ribner, Pack and Hammer, 1996; Sagberg, 1999). This way of asking is sensitive to variations in driving experience, since increasing exposure will increase the likelihood of having fallen a sleep, given a fixed risk per kilometre driven. To correct for years of driving, drivers have also been asked whether they had fallen asleep at the wheel during the last 12 months, and here the estimates range from 8 to 29 % (Gårder and Alexander, 1995; Sagberg, 1999). The differences between the lower and higher estimates are probably related to differences between samples and between countries. For example, the incidence may be higher in large countries with much long-distance driving on monotonous roads, such as the US and Australia.

Copyright © Institute of Transport Economics, 2004



Source: TØI report 739/2004

Figure 1. A conceptual map of fatigue, sleepiness and related phenomena, and their possible precursors and consequences.

Concerning the consequences of falling asleep while driving, a Norwegian study (Sagberg, 1999) showed 4 per cent of the incidences to result in a crash, most of which were running-off-the-road crashes (3.5 %). This is consistent with the finding that the most frequent non-crash consequence was crossing of the right edgeline, which occurred much more frequently than crossing either the centreline or also the left edgeline, as shown in Figure 2.

2.2 THE ROLE OF SLEEP AND FATIGUE IN CRASHES

When it comes to fatigue and sleep as causal factors, there may be different criteria for determining the involvement of those factors. Some studies are based on self-reported information from crash-involved drivers, which can be considered rather reliable if the information is given anonymously. In other studies the data source has been police reports, and there may be some underreporting in such databases. There are also instances where sleep involvement has been concluded on the basis of the trajectory of the vehicle (angle of departure from the roadway), as well as other circumstantial evidence.

On this background it is not surprising that the estimates regarding the role of sleep and fatigue in accidents vary considerably between studies, depending on the criteria used for assessing the causes of the crash. Some estimates for various categories of crashes are shown in Table 1 for drivers in general and in Table 2 for truck drivers in particular.

Copyright © Institute of Transport Economics, 2004

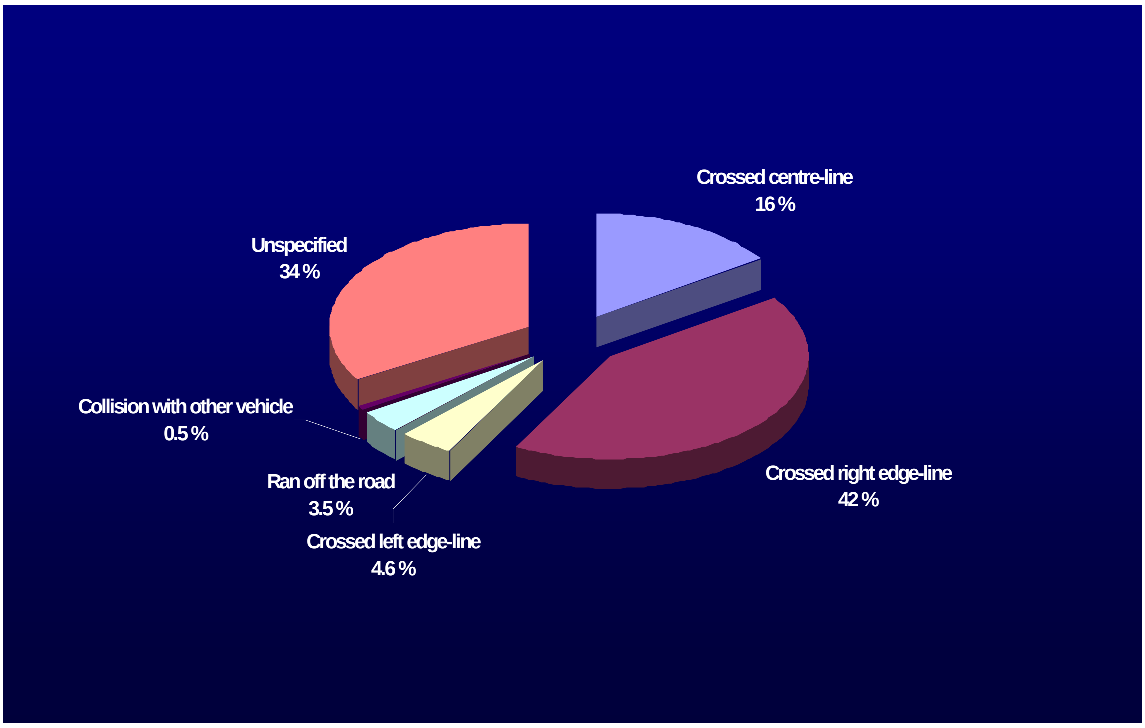


Figure 2. Self-reported consequences of drivers falling asleep. N=1061. (Source: Sagberg, 1999)

Table 1. Driver sleep or fatigue involvement in various categories of road crashes, according to different studies. Proportion of crash-involved drivers judged to have been fatigued or asleep at the moment of the crash. Percent.

Crash characteristics	Proportion related to sleep or fatigue	References
All crashes	1 – 6 %	Fell, 1994; Knipling and Wang, 1995; Pack, Pack, Rodgman, Cucchiara, Dinges and Schwab, 1995; Lyznicki, Doege, Davis and Williams, 1998; TAOKA, 1998; Laube, Seeger, Russi and Bloch, 1998; Sagberg, 1999
All crashes, male drivers	9 – 10 %	Maycock, 1997
Personal injury crashes	7 – 30 %	Sagberg, 1999; UK Department of Transport, 2002
All fatal crashes	3 –15 %	Summala and Mikkola, 1994; Fell, 1994; Pack et al., 1995
Fatal crashes on rural roads	30 %	Fell, 1994
Crashes on major roads	16 – 20 %	Horne and Reyner, 1995; Reyner and Horne, 2002
Head-on collisions	5.6 %	Amundsen and Christensen, 1986
Running off the road	8.3 %	Sagberg, 1999

Source: TØI report 739/2004

Copyright © Institute of Transport Economics, 2004

Table 2. Truck driver sleep or fatigue involvement in road crashes, according to different studies. Proportion of crash-involved drivers judged to have been fatigued or asleep at the moment of the crash. Percent.

Crash characteristics	Proportion related to sleep or fatigue	References
Truck drivers involved in crash	2 – 41 %	Transportation Research and Marketing, 1985; McCartt, Hammer and Fuller, 1998; Arnold, Hartley, Corry, Hochstadt, Penna and Feyer, 1997; Williamson, Feyer, Mattick, Friswell and Finlay-Brown, 2001; European Transport Safety Council, 2001
Truck single crashes	7 – 30 %	US Deparment of Transportation, 1970
Truck drivers in fatal crashes	4 – 31 %	Haworth, Heffernan and Horne, 1989; US National Transportation Safety Board, 1990; Summala and Mikkola, 1994

Source: TØI report 739/2004

Since under-reporting is more likely than over-reporting concerning sleep or fatigue involvement in a crash, the true proportions are probably closer to the upper than to the lower limits of the intervals shown in Table 1 and Table 2.

Despite the large variation between different studies, the following facts seem to emerge:

- Sleep and fatigue are undoubtedly substantial risk factors
- The problem of sleep and fatigue related crashes seems to be larger among truck drivers than among drivers in general
- Male drivers - especially young males - are over-represented in sleep-related crashes
- The proportion of sleep or fatigue involvement seems to increase with crash severity, being highest for fatal crashes
- The proportion of sleep or fatigue involvement is higher on rural and/or major roads than on urban and/or small road

The over-involvement of sleep and fatigue on rural and major roads readily explains the higher average severity of sleep-related crashes, because the roads where drivers are most likely to fall asleep generally are the roads with the highest speed limits, and therefore the consequences of a crash are most severe.

Copyright © Institute of Transport Economics, 2004

2.3 TIME OF DAY VARIATIONS IN SLEEP-RELATED CRASHES

The risk (number of crashes per distance travelled) is clearly highest late at night and early in the morning, as shown in several studies.

Hamelin (1987) found that the relative risk among lorry drivers to have a crash during the night hours (8 p.m. to 8 a.m.) was twice the risk during daytime (8 a.m. to 8 p.m.). He also found that the risk during the night hours increased fourfold if the driver had driven for 11 hours of more. Thus, there seems to be a combined effect of time of day and time on duty. Mackie and Miller (1978) found that the percentage of single-vehicle crashes had a maximum at 4 a.m. and a minimum at 7 p.m., with a 25 times higher risk at the maximum than the minimum. Kecklund and Åkerstedt (1995) also compared risks at different times of the day, taking the traffic volume into account, and found the risk between 3 and 4 a.m. to be 13 times the minimum risk. For fatal crashes with trucks a four times higher risk was found at 5 a.m. compared to 7 p.m. (FMCSA, 2000).

Although the risk is highest during the night, there is also a peak in sleep-related crashes during the afternoon, as shown by Horne and Reyner (1995). Thus, the time-of-day variations in sleep-related crashes mirrors the well-known circadian rhythm, which shows increased sleepiness and reduced alertness not only late at night but also in the afternoon.

It should be noted that although the *risk* of sleep and fatigue related crashes is larger during the night than during the day, the *absolute number* of such crashes is at least as high during the day as during the night, due to the larger exposure during daytime. Therefore, countermeasures against sleep-related crashes should address the problem of falling asleep during daytime as well as during the night.

2.4 CRASH RISK AND PREVIOUS SLEEP

Stutts et al. (2003) found that less than normal sleep the night before a crash increased the odds of the crash being related to fatigue or sleep. Between 6 and 7 hours slept was associated with an odds ratio of 2.58 compared to 8 hours. With less sleep the odds rations increased markedly, up to almost 20 for less than 4 hours sleep.

2.5 CRASH RISK AND TIME ON TASK

Some studies have addressed the question of whether continuous driving for several hours results in increased crash risk. Mackie and Miller (1978) investigated 750 truck crashes and found that the odds of having a crash started to increase after 5 hours, and that the risk during the second half of the drive was twice the risk during the first half. A meta-analysis by Folkard (1997) showed that there seems to be an early increase in risk during the first two hours, followed by a decrease for the next two hours, before it increased again. Another meta-analysis (Elvik, Mysen and Vaa, 1997) found that the risk started to increase notably after 8 hours. The US Federal Motor Carrier Safety Administration (FMCSA, 2000) reported a seven-fold risk increase after 10-11 hours. Although the risk estimates as a function of time vary

Copyright © Institute of Transport Economics, 2004

somewhat, the findings are fairly consistent in showing increased risk with prolonged driving, and they seem to give some support for current regulations of rest breaks during the drive as well as for total daily driving hours for professional drivers. More research is however needed to establish the optimal rest-work schedules.

It should, however, be pointed out that the effect of time on task is mixed up with effects of the time of day as well as the duration of staying awake (and possibly also with previous sleep pattern), so it is difficult to ascertain the effects of duration of driving per se. As pointed out by Hamelin (1987) very long duration of driving has an indirect effect in terms of depriving the drivers of needed sleep, and the factors long hours, night work, and irregular hours tend to interact in their effects on crash risk.

Copyright © Institute of Transport Economics, 2004

3. DAYTIME SLEEPINESS – GENERAL AND CLINICAL ASPECTS[6]

3.1 NORMAL SLEEP

On the average an adult human sleeps 8.1 hours per night, and it is not really understood why we sleep. The famous sleep researcher William Dement has been quoted to say it is to prevent sleepiness (!).

Sleep is not a passive state of withdrawal. It consists of two distinct states of REM (“Rapid Eye Movements”) and nonREM, as first shown in the pioneering work of Nathaniel Kleitman and his co-workers (Aserinsky and Kleitman, 1953; Dement and Kleitman, 1957). Kleitman also investigated the natural sleep propensity and the timing of sleep. He was the first who gave rise to the concept that we have an internal clock, which he estimated to run at 24.5 hours. Research at Harvard has later corrected this to 24 hours 7 minutes. Kleitman got it wrong because he allowed himself to switch on a light in the morning and to switch off the light at night, not believing that the small amount of lux that he was exposed to would have any influence.

REM sleep is the active phase of sleep. The nonREM sleep consists of four stages differentiated primarily by EEG recordings. The various stages of sleep vary from an awake and active high-frequency low-amplitude EEG signal, to the high amplitudes and lower-frequency of stage 4 sleep. The stages are entered in sequences of very orderly transition from awake to slow-wave sleep, most of which happens in the early part of the night. During REM the EEG is similar to that of being awake, and it is sometimes difficult to distinguish awake from REM by the EEG alone. REM is entered every 90 to 100 min throughout the night; this periodicity is a very characteristic feature of sleep. The first phase of REM is short, about 15 min; and the last, which we usually wake up from at the end of the night’s sleep, is the longest, maybe 45 min.

A defining characteristic of REM sleep is an active paralysis of all muscles except the diaphragm and eyes. It is due to a descending inhibition of muscle activity.

There are drives to sleep, such as the circadian drive to sleep, and the homeostatic influence on sleep. Circadian rhythms are the regular occurrences throughout the day (from Latin *circa diem* = around the day), driven by the human internal clock. Several physiological indicators are included in the so-called *hypnogram*, which can be used to demonstrate this sleep-wake cycle. These include hormone levels (growth hormone, cortisol), temperature, potassium, etc. There is a very characteristic fall in temperature with sleep onset, and this is the defining characteristic of circadian rhythms. A person’s circadian rhythm can be established with a rectal temperature probe. Temperature falls by fully a degree centigrade as we fall asleep.

[6] This chapter is based on the workshop presentation by Dr. Adrian J. Williams.

Copyright © Institute of Transport Economics, 2004

People who have been asked not to fall asleep across 24 hrs will have unintended sleep episodes, most often around 6 am, and in the middle of the afternoon or after lunch. This lunchtime propensity to sleep is not related to lunch; it's a circadian process that is independent of everything else. The tendency to sleep is greatest at these two points, and all insomniacs will fall asleep around 5 or 6 a.m., i.e., when there is an inescapable pressure to sleep.

In addition to he circadian influence there is the homeostatic influence on sleep. David Dinges (see e.g. Dinges et al., 2001) in Philadelphia now talks about, not "sleep debt", but too much wakefulness. More than 18 hrs a day will put you into a threatening zone. The longer one is awake after 18 hrs, the more the deficiencies in our performance. This can be shown by the Multiple Sleep Latency Test (MSLT). It consists of giving individuals a nap opportunity every 2 hrs across the day. This can be done after a previous full night's sleep, to establish a baseline, and then with a moderate sleep deprivation of one hour each night for a number of days. Then one will see that a subject over the course of the week will become pathologically sleepy, which is quite arbitrarily defined as an average sleep latency of less than 6 min. So one would be pathologically sleepy with just one hour's lack of sleep at night.

3.2 SLEEP DISTURBANCES AND DISORDERS

In any one year, about 30% of the population complain that they have difficulty sleeping, and 10% have daytime impairment of some sort. *Excessive daytime sleepiness* is prevalent in about 5% of the adult population, as shown by a lot of population surveys.

The most common cause of sleepiness is *insufficient sleep*. A second cause is that sleep may be interrupted, and there are a number of reasons why sleep is interrupted. A third cause is intrinsic sleepiness, for example disorders of the internal clock – a *phase delay syndrome*. So there may be medical problems causing insufficient sleep, apart from the social problems, which of course is the main issue.

Two clinical conditions causing interrupted sleep are of special interest here, *sleep apnoea* because it is so common, and *restless legs* because it is so under-recognized and under-appreciated.

The presence of a phase delay syndrome, a clock problem, is assessed by activity recording across 24 hours, using a piezo-electric crystal device. This sort of problems, the extreme eveningness, not being able to get to sleep, will cause insufficient sleep. So that's a medical problem we should keep in mind. There is a genetic cause for this (Robilliard et al., 2002).

The next thing is whether sleep is interrupted, and I mentioned two conditions in particular. The restless legs syndrome is frequently familial and has a genetic basis underscoring that familial component. It is accompanied almost always (95% of the time) by limb movements in sleep, which the patient is not aware of. The patient's partner may be aware of them, and these twitches disturb sleep and can lead to excessive sleepiness.

Copyright © Institute of Transport Economics, 2004

The other condition is obstructive sleep apnoea/hypopnoea syndrome (OSAHS). There is also a genetic aspect to this condition. An important assessment procedure for this is oximetry, that is, oxygen saturation levels measured at the finger and recorded in a small wristwatch device during the night. In a patient with OSAHS there are repetitive dips in saturation, associated with stopping breathing. There are also great variations in heart rate that accompany the variations in oxygen levels that are part of the condition of sleep apnoea.

Sleep may also be disturbed because of several other diseases, for example, congestive heart failure (CHF), obstructive airways disease (COAS), obesity, and hypoventilation syndrome (OHS). It is notable that one third of the UK and one half of the US are overweight, and 25% of the UK and 33% of the US are obese, defined as a BMI of more than 30. This condition is associated with breathing problems. And the neuromuscular disease Parkinson's disease, and the drugs patients are taking, can also influence sleep.

Finally, there is the problem of intrinsic sleepiness, i.e. something independent of the amount of sleep or whether the sleep is interrupted. Someone may be *intrinsically* sleepy, and that is the condition called *narcolepsy*.

3.3 ASSESSMENT OF SLEEPINESS

There are different methods to assess whether a person who complains of sleepiness is sleepy. First, there are *objective methods*, one of which is the MSLT mentioned above; i.e., taking somebody to a sleep laboratory giving them the opportunity to fall asleep at 2-hr intervals, and within a 20-min period. There is also the Maintenance of Wakefulness Test (MWT), which is the reverse; you ask someone to stay awake for 40 min every two hours. And there are performance tests, like vigilance testing, reaction times, etc. These are labour intensive and not commonly used outside research. The Oxford SLEep Resistance Test (OSLER) is simply the response to light; if one doesn't respond to the light within a predetermined time one is judged to be asleep.

In clinical work, *subjective* assessment methods are more commonly used, trying to capture feelings and symptoms there and then. Commonly used instruments are the Stanford Sleepiness Score (SSS) and the Karolinska Sleepiness Score (KSS), where one asks a person about his/her tendency, intention or potential for falling asleep at that particular moment. The Epworth Sleepiness Score (ESS), on the other hand, is a general assessment of dozing behaviour over the past week or two. The latter is widely used in clinical practice. The ESS is not perfect, by any means; and the reason is that if you ask an individual to estimate his sleepiness there is always the potential for self-denial. And there is also a wide range of normal. The correlation between subjective and objective methods is low – the methods are measuring different things.

Copyright © Institute of Transport Economics, 2004

With ESS the subject indicates his tendency to doze under 8 different circumstances, on a scale of 0 to 3, from never to often. The following situations are listed:

- sitting and reading
- watching TV
- sitting inactive in a public place
- as a passenger in a car for an hour
- lying down to rest in the afternoon
- sitting and talking to someone
- sitting quietly after lunch, without alcohol
- in a car while stopped for a few minutes in the traffic.

The normal is 7 +/- 2, and a score of more than 10 is considered clinically significant.

The ESS is the gold standard of assessment of sleepiness in the clinical world, as imperfect as it is, because the objective methods are too difficult to contemplate.

3.4 CONSEQUENCES OF SLEEPINESS.

There is a lot of evidence that any deficiency in sleep leads to decrement in performance.

Within transport, sleepiness seems to be a particular problem among truck drivers, as shown in several studies (see Amundsen and Sagberg, 2003, for a review of research related to this). Some researchers (e.g. Mitler et al., 1997) have pointed out that the increased prevalence of road traffic accidents in truck drivers as a group may be related to their being more obese, and more sleep deprived perhaps because of having a higher prevalence of obstructive sleep apnoea. And among motorists in general we have seen that a large number would admit to falling asleep at the wheel (see Chapter 2).

A different example showing the effects of sleep loss on work performance comes from at study of surgical residents (Reznick and Folse, 1987). The surgical residents were training the laproscopic techniques, i.e., surgery through telescopes, and they practice on oranges. The number of the errors that the surgical residents made, and the time to complete the task increased after a night on call, and even more after one telephone interruption the night before, compared to their performance when fully rested.

Obstructive sleep apnoea (hypopnoea, reduced breathing or absent breathing syndrome - OSAHS) is a very common problem. It is defined as the coexistence of the complaint of sleepiness with irregular breathing at night. The marker of sleep apnoea is snoring; the process is the same, we only snore because the uvula flaps around in the pharynx, and that only happens if the airway is narrow enough. If the airway were wide open we wouldn't snore. And the narrowing of the airway might proceed to the airway closing off in sleep, which is sleep apnoea. So snoring is one end of a spectrum, being unable to breathe and sleep at all is the other end of the spectrum. Snoring affects around 30% of middle-aged men, whereas the prevalence of obstructive sleep apnoea in the same group is around 4 or 5 %.

Copyright © Institute of Transport Economics, 2004

So this condition will cause sleepiness in a large number of drivers. The minimum diagnostic criteria for clinically significant OSAHS are that someone has more than 15 stopped or interrupted breaths per hour of sleep, along with sleepiness or at least two of the following symptoms:

- snoring
- unrefreshing sleep
- choking
- interrupted sleep
- restless sleep
- nocturia
- impaired concentration
- irritability, personality change
- decreased libido

Since a large proportion of middle-aged persons have at least two of these symptoms, the presence of interrupted breathing is almost guaranteed to imply an OSAHS diagnosis.

The sleepiness is assessed by the ESS. If sleepiness is greater than ten, or even if it is less than ten and the individual is involved in dangerous occupational situations, it is considered clinically significant.

Further assessment may be simple or complex, a hospital study or at home. The most complex method is *polysomnography*, that is recording of several physiological variables during sleep, including EEG, respiration (both chest and abdomen), heart rate, and oxygen saturation. With this method one can measure sleep and know what state somebody is in, whether they are in REM or nonREM, and how much of a breathing disturbance they might have. The oximetry (oxygen saturation measure) has been shown to have a sensitivity of 81 % and a specificity of 65 %. The oximetry cannot, however, exclude OSAHS; there is a false negative rate of up to 1/3.

Any tendency to stopped breathing in sleep first begins in REM sleep, because most muscles are paralysed in this stage of sleep.

3.5 TREATMENT

There are different methods for treating OSAHS, which have proven effective. Randomised control trials with treated patients have show benefit from treatment, in terms of improvement in sleepiness, simulated driver performance, quality of life, blood pressure, and mood.

The first choice concerning treatment is the *continuous positive airway pressure* (CPAP). This is providing air pressure through a nose mask, which splints the upper airway; it creates access, a pneumatic splint, keeping the airway open by positive pressure applied through the nose. The effect of CPAP when used appropriately is dramatic, and improvements in ESS, MWT and a measure of life quality have been demonstrated.

Copyright © Institute of Transport Economics, 2004

This means that a person's pathological sleepiness can be normalised with this standard treatment. It is recommended to use the device for the whole night. The more the person uses the device, the greater the fall in the Epworth sleepiness score.

If there is an insufficient response to the CPAP, an alternative medical treatment is Modafinil, which is described as a wake-promoting drug, developed for narcolepsy, released in France about 20 years ago, in UK 10 years ago, and in the US 8 years ago. It is now being used for shiftworkers, for people with obstructive sleep apnoea, whose treatment is not proving successful, and for narcolepsy. And in the States they are about to get indication for sleepiness. The drug is also taken by Stealth bomber fighter pilots.

There is only one other treatment to help keep the upper airway open. And that is an oral appliance, which helps holding the lower jaw forward during sleep, and in doing so brings the tongue forward, and opens up the posterior pharynx. It is useful, not as good as the CPAP, but it is the alternative that is used in clinical practice.

3.6 OSAHS AND DRIVING

It is known that accident rates are increased in people with obstructive sleep apnoea. There is a report from Spain in which 100 or more individuals who presented in the emergency room after an accident, were assessed as to whether they had OSAHS. And the prevalence of OSAHS was 6 times that in another population of non-crash people. And as mentioned earlier, treatment with CPAP will improve driving as evidenced by simulator performance. For other results we refer to a review by Connor et al. (2001) of epidemiological studies of sleep disorders and accident risk.

In the UK, the DVLA ("Driver and Vehicle Licensing Agency") rules have recently been rewritten, and this has some implications for patients with OSAHS. When receiving the diagnosis, the patients are told that they have to inform the driving licence agency that they have a sleep disorder. And the information also goes in writing to the general practitioner. The drivers are further recommended to tell the insurance company. In the case of "continuing excessive awake-time sleepiness"[7] driving must cease. The rules say that for a simple licence driving will be permitted when control of symptoms is *achieved*, for a HGV license when control of symptoms is *confirmed*. This means that for the simple license it is simply the responsibility of the drivers themselves not to drive when sleepy. So they have the complete control of whether they drive or not, realising that if they have an accident they would be considered liable. But "confirmed" means by a physician. It can, however, be argued that the decision about a HGV license is also patient determined, since the only way the physician can confirm the sleepiness is by asking the patient.

[7] The phrase "*awake-time* sleepiness" rather than "daytime sleepiness" is used to include the shift-workers, who are supposed to be awake during night-time.

Copyright © Institute of Transport Economics, 2004

3.7 INTRINSIC SLEEPINESS - NARCOLEPSY

Narcolepsy is also termed intrinsic sleepiness, because it is genetic. Recent research has revealed the neurophysiological mechanisms underlying this disease. It has been shown that narcolepsy has a Mendelian inheritance in animals. And it affects several animals, including horses. In humans it is linked to an HLA[8] type (DQ1 *0602), implying that there is a genetic influence in humans. This particular HLA subtype is very common, being present in one quarter of the population. In narcoleptics, however, it is present in almost 100 %. So there is a predisposition to getting narcolepsy if one has this genetic HLA type. This knowledge has been achieved through two unrelated research efforts, which have as a focus the publication of the human genome. In 1999 about 500 or more peptides were identified with no known function. And one of them was called *orexin*, from the Greek for appetite, because the peptide had similarities to appetite substances that were known. It was also called *hypocretin*, because it is found only in the hypothalamus and has some resemblance to the hormone secretin.

In humans, narcolepsy has a prevalence of one in 2000. This means that narcoleptics make up a rather small proportion of the driving population, but in view of the nature of their condition, they are probably at a very high risk, and it is therefore important that the condition is properly diagnosed and treated.

[8] HLA: Human Leukocyte Antigen

Copyright © Institute of Transport Economics, 2004

4. PRECURSORS AND INDICATORS OF DRIVER FATIGUE AND SLEEPINESS. SIMULATOR STUDIES.[9]

4.1 THE SIMULATOR AT CNRS-CEPA

Recording drowsy drivers in a simulator is of course much safer than recording a drowsy driver on the road. It is comparatively easy in the laboratory to have sleep-deprived people, to use alcohol, to use medications, to shift the time for sleep period, to have people sleeping during the day and be active during the night, and so on. Although simulator driving is far from real driving it has important similarities to real driving situations, and it is the only possible way to approach some particular driver states, especially those that are very dangerous in real traffic. The following research is based on the simulator at CNRS-CEPA. This simulator consists of a real car cut behind the two front seats. It has three moving platforms, so it reproduces most of the movements of a real car. In front of the car there is a 3-screen system, which gives about 120 degrees viewing angle. And there are plans to add two other screens on the sides, in order to get a 180 degrees viewing angle. There is a driver seat and a passenger seat, and in some experiments recordings are made from both the driver and the passenger. The system is totally interactive, so the actions on the commands of the car will modify the position of the car as well as the picture on the screens. The car is equipped with the usual instruments and the usual commands. There are video cameras to record both the driver and the traffic scene. Different sensors give indications on driving performance, for example steering wheel movements, pressure on the steering wheel, pressure on the pedals, and changing gears. The steering wheel grip sensor gives an idea of how people handle the wheel, and what effort is exerted. The driving performance data also include speed, lateral position and time to line crossing (TLC). The TLC is the time taken to cross the line if the vehicle keeps the same speed and heading. Ambient temperature in the car can be varied from 10 to 50 ^{o}C, in order to study the impact of temperature on the level of vigilance of the driver.

Of special relevance for the study of vigilance is the possibility of recording physiological data, including EEG recordings, vertical and horizontal eye movements, EMG of the chin, ECG, and respirogram. In some experiments also deep body temperature and skin temperatures are recorded. All these data are collected online in order to detect drowsiness

Blinking activity is more defined when people are starting to fall asleep; blinks are longer, and some time they go to eye closure. Heart rate, respiratory rate and EMG cannot be used alone to indicate hypovigilance, but in complement with all other physiological measures they can bring new ideas and confirm some data

The simulator studies are complemented with the use of questionnaires. And the questionnaire mainly used for assessing drowsiness is the Karolinska Sleepiness Scale (KSS), developed by Torbjørn Åkerstedt and his group (Åkerstedt et al., 1979). This is used continuously throughout the experiments.

---

[9] This chapter is based on the workshop presentation by Dr. Alain Muzet.

Copyright © Institute of Transport Economics, 2004

The scale goes from level 1, which is "very alert", to level 9, which is "very sleepy, great effort to keep awake, fighting sleep". Until level 5 we cannot say that people are sleepy or are dozing, but as soon as you reach level 6, "some signs of sleepiness", then you have increasing sleepiness and drowsiness. The subject is asked every 10 minutes to give the number that correspond to his or her level of sleepiness at the time of the question. And as they have been trained to know exactly what the levels correspond to, it is quite easy, and it is not disturbing for them to answer this question.

Behavioural measures are collected together with the physiological ones, like eye closure, low muscle tone, gaze deviations, yawning, change in body posture, and self-centred movements, which can be seen from the video taken in front of the driver. The research has shown that especially change in body posture and self-centred movements are increasing when people become drowsy.

From the physiological and behavioural recordings the driver’s level of vigilance as well as the direction of his gaze can be monitored. The EEG is an important source of data on the level of vigilance. In the recordings from a fully awake driver one can observe the low-amplitude fast *beta* activity. When the driver gets drowsy, the beta is gradually replaced by the *alpha* (8-12 Hz) and *theta* (4-7 Hz) activity.

Simultaneously with the appearance of alpha activity one can observe a modification of the shape of the blink, which is another important indicator of drowsiness. A normal blink will last roughly from 150 to 200 milliseconds. And it is very clear to recognise a person from his or her blinking activity. We have a very particular way of closing the eyes. When the driver gets drowsy a wider blink curve can be observed, which means that the blinking activity has been slowing down. With increasing drowsiness eye closure is observed. In the simulator drivers will exhibit total eye closure for extended periods while sitting at the wheel, still driving, in which case any oncoming event or a curve will be followed by an “accident”.

Additional evidence to verify the occurrence of eye closure comes from the video recording of the driver. Thus the duration of eye closure can be computed.
An objective sleepiness score has been developed, which takes into account the presence or absence of alpha and theta waves, and also their relative power. The score varies from level 0, which means no sleepiness at all, to level 4, which indicates a very sleepy driver. Ordinarily the score is computed every 20 seconds throughout an experimental session.

4.2 SOME RESULTS

A series of three experiments investigated effects of driving at night. In the first experiment one compared the way people were driving on lighted vs. non-lighted freeways. And the main result was that on lighted freeways, people were reacting to upcoming events longer in advance than on non-lighted freeways. So, lighting was beneficial in the sense that the subjects could anticipate better in the lighted situation - while this was more difficult in the non-lighted situation.

Copyright © Institute of Transport Economics, 2004

The second experiment compared drivers driving for 3 - 3.5 hours - a 350-kilometre drive - starting at 1 a.m. and finishing around 4 - 4.30 a.m. One group of drivers were driving on a non-lighted freeway from the start to the end of the trip, while another group drove on fully lighted freeways. The results showed that there was no difference in average speed between the two groups over the 3.5 hours of driving. And there was no difference at all between the groups in the way drowsiness occurred during the drive. So whether the freeway was lighted or not did not change anything in the way people were becoming progressively more and more drowsy. This was quite interesting, because the hypothesis was that people driving in a lighted freeway would take more time to become drowsy.

In the third experiment the drivers were driving on non-lighted freeways. After about one hour they arrived at a lighted section, which lasted for 10 kilometres, and after another hour of driving there was a second lighted area of 20 kilometres. This was to study the impact of arriving in a lighted area - would it reactivate the driver or not? The sleepiness scores tended to be reduced very much on arrival at the first lighted section, implying that the subject was somewhat reactivated. But the activating effect did not last very long - only for another 10 or 15 kilometres, after which the vigilance decreased again. The most interesting finding was that the second lighted area did not have any activating effect on the driver. It seems as if the level of drowsiness after extended driving was too high to be reactivated by this second lighted area.

Changes in the average lateral deviation of the car was measured in an experiment involving non-stop driving for six hours. Increased lateral deviation indicates a degradation of the driving quality. The lateral deviation started to increase considerably after the fourth hour of driving. EEG was also recorded, and absolute theta power – which is supposed to reflect drowsiness – also showed an increase, which roughly paralleled the change in lateral deviation. But there was one important difference: The theta would start to increase *before the lateral deviation is modified*, so it is a good sign that something is going to happen. Concerning the alpha power, it tended to increase almost continuously during all the drive. So, somehow there is some parallelism between these physiological measures and the driving performance.

Several behavioural signs seem to be characteristic of a driver proceeding from being somewhat drowsy to falling asleep at the wheel, based on video recordings in the simulator. Yawning is very typical. Eye closure lasting longer and longer may follow. Changes in body posture are frequent, as well as self-centred movements like touching one's face or scratching oneself. This may go together with prolonged eyes closure, and is a very important sign, indicating low vigilance occurring while driving.

Using difficult situations like, for example, a parked car suddenly starting from the side of the road is an effective way of demonstrating prolonged reaction times in drowsy subjects. Although drivers may have stronger motivation to maintain vigilance during real driving than in a simulator, the experiences from the simulator experiments can do doubt be validly generalised and give important suggestions regarding countermeasures against driver fatigue.

Copyright © Institute of Transport Economics, 2004

5. THE SENSITIVITY AND SPECIFICITY OF EYELID MEASURES, DRIVERS' EXPERIENCE OF FATIGUE, AND IMPLICATIONS FOR COUNTERMEASURES[10]

5.1 EYELID MEASUREMENTS

When dealing with the energetic base of performance one has to discriminate between the following different phenomena, all of them characterised as processes in time:

- Impairment of vigilance: A diminished state of readiness to react.
- Fatigue: Weariness of exhaustion from labour, exertion or stress.
- Drowsiness, sleepiness: Inclination to fall asleep.

Impaired vigilance is mainly caused by task characteristics, fatigue is caused by time on task, and sleepiness insufficient sleep and other factors mentioned previously. The most obvious countermeasures are variation in task for impaired vigilance, rest for fatigue, and sleep for sleepiness.

It should be noted, however, that those states are not independent, e.g. sleepiness may lead to impaired vigilance independently of variations in task characteristics.

Concerning measures of energetic states, the following characteristics and limitations are notable:

- Measures differ in their sensitivity and specificity for different states.
- Measurements from different domains (e.g. subjective vs. physiological vs. behavioural measures) often correlate poorly.
- Measurements are often intrusive, altering the state to be measured.
- Measurements may need complicated technological devices and cannot be applied in working environments like driving.

The research to be reported in this chapter has its focus primarily on eyelid measurements as indicators of drowsiness. Different parameters of eyelid activity can be measured, and they reflect partly different phenomena and influences.
Blinking frequency increases with time on task and decreases with task difficulty. *Blinking duration* increases with sedating or relaxing substances and with increasing daytime sleepiness (caused by circadian rhythm and/or OSAHS); there is a gradual transition to *long eye closures*. *Eyelid opening level* increases with visual attention and orientation.

The research of the Würzburg University Centre for Traffic Sciences seems to indicate that the different parameters of eyelid measurements are controlled by different physiological processes and are sensitive to different energetic states.

---

[10] This chapter is based on the workshop presentation by Dr. Professor Hans-Peter Krüger.

Copyright © Institute of Transport Economics, 2004

The eyelid activity is measured by adhering induction copper coils to the eyelids, measuring opening level with a resolution of about 0.1 mm, and with a sampling frequency of 100 Hz. An example of the recording is shown in Figure 3.

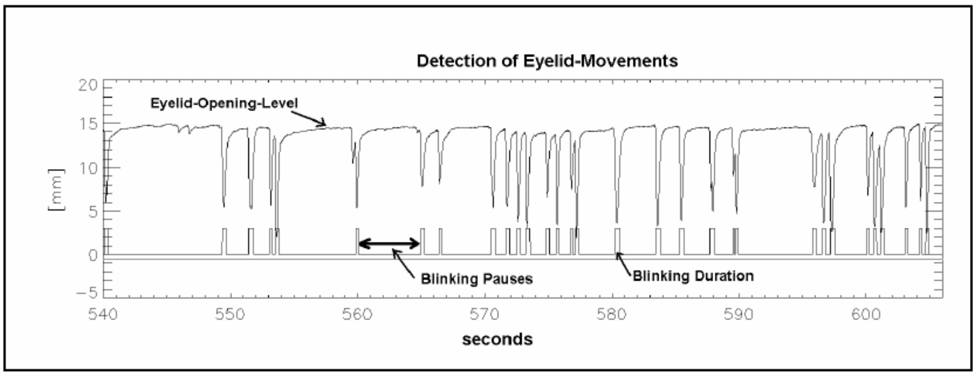


Figure 3. Sample output from eyelid recording (Source: Hans-Peter Krüger)[8]

The eyelid recordings are supplemented by computerised analyses of video recordings of the driver.

On the basis of eyelid measurements four different stages are distinguished, shown in Table 3. It appears that increased blinking frequency is the earliest eyelid indicator of impaired vigilance, which identifies stage 1. Prolonged blinks in addition identify stage 2. Stage 3 is defined by small eyelid opening level in addition (or microsleep or very long closures).

Table 3. Stages of vigilance (fatigue index) and the resulting driving performance (Source: Hans-Peter Krüger)

	Stage 0: Awake	Stage 1: Hypovigilant	Stage 2: Drowsy	Stage 3: Falling asleep
eyelid opening	wide open	wide open	half closed	nearly closed
blinking frequency	low	high	high	high
blinking duration	short	short	long	long
tracking performance	excellent	good with lapses	bad	catastrophic

There is a significant correlation between the fatigue index shown in Table 3 and the amount of alpha activity in the EEG. And as shown in the table, there is a relationship with tracking performance in simulated driving. There is also a progressive increase in misses on a vigilance task across the stages, and a co-variation between fatigue index and SDLP (standard deviation of lateral position). It

Copyright © Institute of Transport Economics, 2004

has also been shown that the time course of the fatigue index after ingestion of alcohol tends to parallel that of the blood alcohol level.

The following conclusions are warranted on the basis of the research using eyelid measures:

- Eyelid movements are characterised by at least two different processes:
    - Blinking pauses as an indicator of attention or vigilance
    - Blinking duration and opening level as an indicator of fatigue and sleepiness
- At least four stages of fatigue can be defined if these parameters are evaluated with respect to the individual characteristics of blinking behaviour.
- Significant differences between these stages were found in
    - physiological measures
    - parameters of performance
    - subjective reports

5.2 THE STRUCTURE OF SUBJECTIVE SYMPTOMS OF FATIGUE

To study how drivers handle their fatigue and sleepiness, research was carried out to establish the drivers' mental model of their energetic state, in other words, how they experience their fatigue, or how they appreciate various subjective symptoms.

First, a list of fatigue-related symptoms reported by drivers was collected from the research literature, and the symptoms were ranked according to their frequency. A group of experts then grouped the symptoms into four categories: 1) driving style symptoms, 2) emotional/motivational symptoms, 3) cognitive/mental symptoms, and 4) somatic symptoms, with four symptoms in each category.

In the next step, the categories were judged by 30 drivers on a time scale from 1 (=awake) to 10 (=just before falling asleep), with respect to the time of the occurrence of the symptoms, and their duration. Taking the beginning and end values of the occurrence of each symptom as variables a cluster analysis was performed, yielding three time clusters of fatigue stages.

The first cluster had average start and end scale values of 3.4 and 7.4, and included the following four symptoms: bored, angry, wandering thoughts, and careless driving.

The second cluster had start and end scale values of 5.0 and 9.3, and included nine symptoms: lack of energy, lethargic, impaired concentration, mental slow down, blackout or loss of memory, slight driving errors, and clumsy driving.

The third cluster had starting and end values of 6.6 and 10, and included five symptoms: heavy lids, burning eyes, shivering, accommodation problems, and lane keeping errors. It is notable that all the somatic symptoms were reported to occur in the last stage before falling asleep.

Copyright © Institute of Transport Economics, 2004

5.3 DRIVER-INITIATED COUNTERMEASURES

The approach used for assessing the countermeasures drivers use against fatigue, was similar to the symptom assessment described above. Reported countermeasures were collected from the literature, and ranked. They were grouped by experts into five categories: 1) driving, 2) cognitive top down, 3) cognitive bottom up, 4) somatic external, and 5) somatic self-stimulation.

Like the symptoms, the countermeasures were also scaled for the time of their occurrence and duration during the development of fatigue.

Taking the beginning and end of the occurrence of countermeasures as variables, a cluster analysis was performed, yielding four clusters.

Cluster 1 had average start and end values of 2.7 and 5.4 and included only cognitive top down countermeasures: problem solving, watching environment, thinking about everyday problems, and observing others.

Cluster 2 had average start and end values of 3.4 and 6.2, and included three countermeasures: phoning, driving faster, new driving tasks.

Cluster 3 had average start and end values of 3.2 and 8.5 and included listening to the radio, communication with passengers, drinking coffee, drinking softdrinks, and chewing gum.

Cluster 4 had average start and end values of 5.4 and 8.7 and included several countermeasures occurring rather late in the development of fatigue: open window, loud radio, stretching muscles, moving on the seat, touching face, just following other vehicle, and slowing down.

With increasing fatigue the countermeasures appear to change along four different dimensions:

- from top-down to bottom-up
- from internal to external stimulation
- from cognitive to somatic measures
- from increasing to decreasing driving difficulty

Combining these dimensions, the various categories of countermeasures will occur in the following sequence as fatigue develops, as shown in Figure 4:

- Cognitive top-down
- Increasing driving task difficulty
- Cognitive bottom-up
- Self-stimulation
- Somatic external
- Decreasing driving task difficulty

Copyright © Institute of Transport Economics, 2004

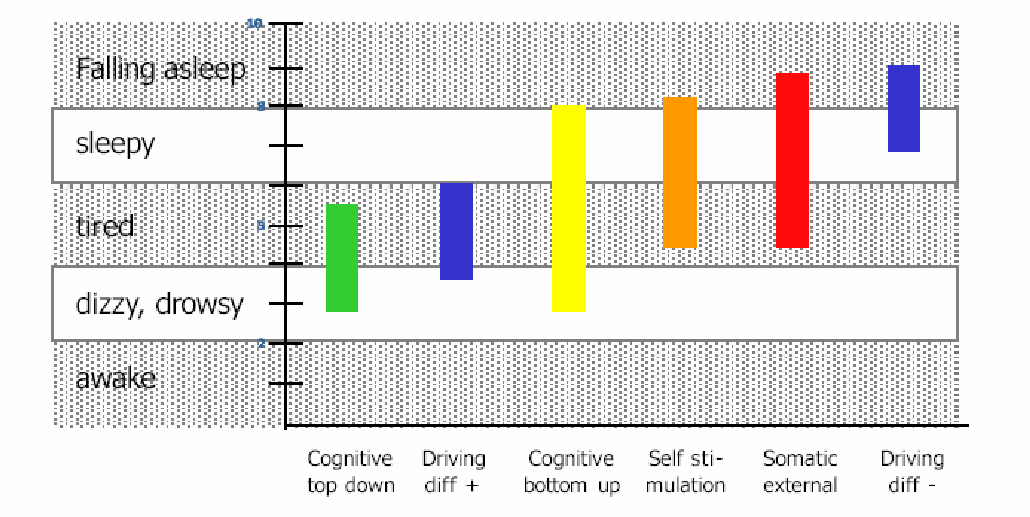


Figure 4. Time sequence of main categories of individual efforts to prevent fatigue (Source: Hans-Peter Krüger)

5.4 OPERATIONAL COUNTERMEASURES

On the background of the driver's appreciation of his/her fatigue symptoms and their efforts to manage these symptoms (as shown in Figure 4), operational countermeasures (in-car technical systems) should have the following aims.

- Support the individual effort to maintain performance
- Protect the individual in case of failures of his or her management system

The following available measures are relevant for these purposes.

- Information systems
  - Radio and internet offers can be personalised
  - Navigation systems with information about actual location
- Warning systems
  - Collision warning
  - Road departure warning
  - Alertometer (detecting vigilance decrements)
- Supporting systems
  - Heading control with torque on steering wheel preventing lane departure
- Substitution systems
  - Automatic cruise control
  - Automatic lateral control
  - Automatic driving in stop-and-go situations

The countermeasures should be adjusted to the various phases of fatigue as described above, and to the corresponding symptoms and individual efforts being taken by the driver. On this background the following phases of information, warning,

Copyright © Institute of Transport Economics, 2004

support, and intervention from technical systems can be described: 1) preserving phase, 2) phase of low stimulation, 3) phase of high stimulation, and 4) phase of protection.

The *preserving phase* is connected to the cognitive top down efforts of the driver, and aims to preserve performance as long as possible, by for example:

- Substituting part tasks (automatic cruise control, heading control) to make driving easier without underload
- Offer information and occupation
- Protect the driver from distraction, by warning systems

The *phase of low stimulation* is focused on the drivers' effort to increase driving difficulty or using cognitive bottom up countermeasures, and the operational countermeasures should aim to stimulate the driver by increasing driving difficulty. Examples include:

- Feedback about actual performance
    - Visual feedback about lane keeping accuracy
    - Acoustic feedback
    - Haptic feedback of lane departures
- Change parameters of assistance systems in direction of less comfortable
    - Heading control: Increase steering torque
    - Adaptive cruise control: Amplify kinesthetic feedback of system actions (stronger acceleration/deceleration)

The *phase of low stimulation* corresponds to the drivers' efforts at self-stimulation and somatic external countermeasures. The operational countermeasures in this phase should support the driver by strong stimulation and further increase of driving difficulty, including for example:

- Try to hold the driver in the loop
    - Switching off substitution systems like ACC
    - Introduce controlled disturbances
- Change vehicle parameters in direction of less comfort
    - Increase steering torque
    - Reduce spring suspension
    - Amplify motor sound
- Introduce kinesthetic stimulation
    - Vibration of the seat and massage
    - Vibration of the steering wheel

The *phase of protection* concerns operational countermeasures to be activated when the driver is close to falling asleep, and efforts to reduce driving task difficulty are predominant. The countermeasures should advice the driver to stop and should go back to strong warning, like

- Setting all systems into their warning mode
    - Adaptive cruise control into longitudinal warning
    - Heading control changes into lateral warning

Copyright © Institute of Transport Economics, 2004

- Sharpening all warning systems
    - Lower the criterion for warning
    - Increase amplitude
- Giving feedback about increasing frequency of warning signals

Additional possible countermeasures, which however are questionable, could be reduced engine power and/or automatic stop.

The effectiveness of the mentioned countermeasures is still an open issue. There are arguments both pro and con. The main argument in favour of such countermeasures is that drivers normally get too little information about the quality of their driving and therefore overestimate their capabilities. Information about the own state and about performance level together with supporting technical systems are therefore likely to be helpful.

On the other hand, we will never have a perfect measuring system. There will always be false negatives (missing alarms). Reducing the false negatives means increasing the false positives, which may reduce the efficiency of the warnings.

Furthermore, the time course of fatigue is different between persons and even varies from time to time for the same person.

Copyright © Institute of Transport Economics, 2004

6. DRIVER WARNING SYSTEMS – THE AWAKE PROJECT[11]

An EU project focusing more particularly on the issue of how to utilize in-car information technology to help drivers maintain high vigilance while driving, is the AWAKE project.

The AWAKE is a part of the IST programme of the European Commission. It started in September 2001 and has a duration of 3 years, with a budget of over 6 million euros. The partners are major automotive system developers, research institutes, university institutes, and also immediate users, car manufacturers, and end users.

The automotive system developers include Siemens VDO, Actia, Autoliv, and Navigation Technologies. The European research institutes include the Hellenic Institute of Transport HIT, TNO in the Netherlands, the Swedish Road and Transport Research Institute in Linköping, and ICCS, which is in Greece, the French institutes CNRS-LAAS and CNRS-CEPA, CARA-BIVV in Brussels, and the Netherlands' Research School for Transport, Infrastructure and Logistics TRAIL. Then there are two universities, the University of Stuttgart and COAT Basel in Switzerland, and the car manufacturers Fiat in Italy and Daimler-Chrysler in Germany. The end users are the FIA (Fédération Internationale de l'Automobile) and the AIT (Alliance Internationale de Tourisme).

The background of AWAKE is the large number of crashes that are due to driver drowsiness or fatigue. It has been reported that fatigue or drowsiness of the driver cause about one third of accidents on French highways during the period 1979-94. And about 40 % of fatal accidents on US highways were sleep-related or low vigilance related. Fatigue is estimated to be a factor affecting 30 to 40 % of heavy truck crashes in the US, and drowsiness is known to cause about 10 % of all accidents and fatalities (see also Chapter 2). So the aim of AWAKE was to develop an unobtrusive and reliable system, which can monitor the driver and the environment, and detect in real time hypovigilance based on multiple parameters, operating in all highway scenarios. The target goals for the usability of the system are:

- reliability level over 90 %
- false alarm rate below 1 %
- user acceptance over 70 %
- HMI perception rate over 90 %.

The project has several specific aims regarding system development:

- To develop a multi-sensor system (eyelid camera, steering grip sensor, lane tracker, and other vehicle-related parameter monitoring sensors).
- To develop parallel stochastic and deterministic (knowledge-based) approaches.
- Extension of current diagnostic methods to take into account continuous diagnostic capabilities (incremental learning).

[11] This chapter is based on the workshop presentation by Dr. Alain Muzet.

Copyright © Institute of Transport Economics, 2004

- On-line personalisation of the diagnostic algorithm.
- Introduction of ambient intelligence to the diagnostic module according to the traffic environment and the driver's attention to it (through gaze analysis).
- Development of a warning strategy that combines acoustic, visual and haptic elements and is parametric to drivers' vigilance state as well as to the estimated traffic situation. So it should take into account both the driving environment and the capacities of the driver.
- Parametric specifications (to match the particular preferences of the target user cohorts, i.e. young drivers, professional heavy vehicle drivers, shift workers and people suffering from sleep disorders).

The following system components are supposed to achieve the goals of AWAKE:

- Hypovigilance diagnosis module (HDM)
- Traffic risk estimation module (TRE)
- Driver warning system (DWS), using acoustic, visual and haptic means in various levels of warnings according to inputs from the monitoring modules.
- Hierarchical manager (HM) to perform self-diagnosis and co-ordinate the other system components.

The system includes environmental sensors (to detect rain, night, fog and so on), vehicle sensors, and then the hypovigilance sensors for the driver. There are connections between the traffic risk estimation module, the driving identification system, the hierarchical manager, and the hypovigilance diagnosis module, and from these modules to the driver warning system, which is turned on if necessary to alert the driver.

The HDM is a very important module because it has to detect and diagnose driver hypovigilance in real time, based on an artificial intelligence algorithm. It fuses data from on-board driver monitoring sensors (eyelid and steering grip data) and data regarding the driver's behaviour (lane tracking, accelerator/brake and steering position data). It will be adapted to the specific driving characteristics of the user by continuous driver monitoring and expert-based adaptation.

The traffic risk estimation module will assess the traffic situation and the involved risks. It matches, following a deterministic approach, data from an enhanced digital navigational map, a positioning system, an anticollision radar, an odometer, and a driver's gaze direction sensor. Its output is used by the HDM to re-assess the state of the driver, and by the driver warning system to determine the adequate level of warning.

Then, finally, the driver warning system is to warn the driver safely and in time about his or her reduced vigilance according to the traffic situation, his or her hypovigilance state, and the driver's type (for specific driver cohorts), and to effectively support the driver regarding the appropriate course of action and minimise the risk of information overflow in a critical situation.

Copyright © Institute of Transport Economics, 2004

The AWAKE includes several system test-sites and demonstrators.

- There are 18 pilot studies in 7 countries.
- 3 vehicle demonstrators (a city car, a luxury car and a truck demonstrator)
- 3 more prototype vehicles for measurements.
- The system is tested in 5 driving simulators, including a heavy vehicle simulator and a virtual reality simulator.
- Tests also with specific user groups (young males from 18 to 24, shift workers, elderly drivers, sleep apnoea syndrome patients, professional drivers).

The demonstrators are a city car (Fiat Stilo), a luxury car (Mercedes E class), and a truck (Mercedes Actros).

Further information about the AWAKE project can be found on the project website http://www.awake-eu.org/.

Copyright © Institute of Transport Economics, 2004

7. MANAGING OCCUPATIONAL DRIVER FATIGUE: RAISING AWARENESS, REDUCING RISK[12]

This chapter describes an example of an approach to transform scientific knowledge about driver fatigue and sleepiness into practical solutions for occupational drivers.

Awake Ltd (which has nothing to do with the AWAKE project described in the previous chapter) is an organisation working in the field with fatigue management programmes in occupational settings. The company was established by Dr. Jim Horne at the Loughborough University Sleep Research Centre, and there is close co-operation between the two organisations. The Loughborough Sleep Research Centre is one of UK's leading laboratories for research into sleep, especially related to driver fatigue. The sleep research team at Loughborough work regularly as advisors to government and the police, and serve as expert witnesses on sleep-related accidents. One important accomplishment of this group is to establish a set of criteria for distinguishing sleep-related accidents from other types of accidents. Awake was set up in 2001 in response to the many calls for assistance Loughborough received from various companies. The main purpose of Awake was to turn the results from academic research into practical solutions for companies. More specifically, the aims are to help organisations manage fatigue, and thereby improve performance, reduce accident risk and improve quality of life. Most of the customers are companies that have much to lose from accidents, e.g. petrochemical companies having large fleets of tanker drivers. The services are tailored to suit the constraints of the companies, such as difficult shift systems, which pose special challenges regarding fatigue management.

The main aim of fatigue management is to raise the awareness of drivers and shift-workers of the dangers of operating whilst tired. A special problem is that professional drivers consider themselves as experts on driver fatigue, since they experience it often, and a main role is to challenge and counteract some of the mistaken beliefs people have about driver fatigue. In addition to challenging these myths it is important to provide the drivers with effective solutions. To get through with the message it seems to be easier to focus on the importance of well-being and life quality in addition to risk reduction.

Driver fatigue prevention should be considered a shared responsibility between management and the drivers. The management is responsible by law for the health and safety of their employees, and for organising the work accordingly. Important instruments for this purpose are trip scheduling, work predictability and pay systems. The role of the policies and practices of transport companies in hindering or promoting the management of driver fatigue has been investigated in a recent study by Arnold and Hartley (2001). They concluded that current managerial practices regarding driver fatigue leave much to be desired. Few companies had a clear policy for managing fatigue, and among those who had a policy, the potential benefit was compromised by operational practices, such as failing to communicate driving time limits to drivers, or taking action in case of violation. Adequate training is also an

[12] This chapter is based on the workshop presentation by Dr. Paul Jackson.

Copyright © Institute of Transport Economics, 2004

important part of the companies' duty of care to provide safe working places in accordance with the Occupational Safety and Health legislation.

Drivers on their side are responsible for being fit to drive, which implies getting sufficient rest and sleep, and also to take care that their life outside work does not interfere with this aim.

The Awake "Tiredness management programme" has three target groups: the drivers, their families, and the management, and it aims at giving a powerful and consistent message implying that excessive daytime sleepiness should not be tolerated, and that it can be prevented. Fundamentally, the most important group to deal with, and whose misconceptions need to be challenged are those in management. Managers will rarely appreciate the extent to which their drivers are suffering from fatigue.

A credible, authoritative training is aimed at, and to achieve that, a team of former traffic police officers is engaged in the training together with the people from Awake. The presentation and discussions of the fatigue issues is supported by information material like CDs, posters, leaflets, guides and videos (from the police and others). Information about accidents is presented together with interviews or presentation of personal experiences of persons who have been involved in fatigue-related accidents. An important element of the training is to have the participants present and discuss their own personal experiences regarding fatigue and driving.

Emphasis in put on challenging misconceptions regarding which measures work and which measures don't work, when it comes to the prevention of falling asleep. The drivers are advised not to rely on the warning devices that are in use, like sensors to detect when the head is nodding or the driver slumps forward in the seat, devices to monitor eye blinking/closure, physiological sensors, or reaction time monitors. The message that is conveyed is that those measures "won't stop you falling asleep at the wheel". Although some of them may actually wake up a driver who has fallen asleep or is about to fall asleep, it is considered important to give a very clear and unambiguous message to professional drivers that they should not drive while fatigued.

A "problem" may be that professional drivers consider themselves experts on driver fatigue, and have developed their own solutions that they believe in. Some of the private countermeasures that have been reported are quite bizarre, like:

- sucking lemons
- sticking pins in your wrist
- holding money out of the window
- recounting past romances
- shaking your head violently
- putting your hair up in the sun roof

Copyright © Institute of Transport Economics, 2004

To make drivers focus on the precursors of falling asleep they are asked to report whether they would take a break when experiencing each of the following symptoms:

- find it difficult to concentrate
- keep adjusting the driving position
- repeatedly stretching and yawning
- head is nodding
- fighting to keep eyes open

A simulator study at Loughborough University investigated the effects of various countermeasures drivers commonly use, like winding the window down, turning the radio up, chewing gum, etc. and showed that such measures can keep a driver awake for 5-10 minutes at best. Videos taken from drivers in such experiments are shown to real drivers in order to call their attention to the danger of not relying on the various early signs of falling asleep. After seeing the video, drivers are again shown the list of symptoms, and the intention is to make them appreciate the earliest symptoms, on the top of the list, as signals to take a break.

A further element in the courses for drivers is to increase their awareness about how to get sufficient amount and quality of sleep, and about the possible sleep disorders, which were described in chapter 3, in order to make drivers who suspect that they suffer from any such disorders consult their doctor.

Awake Ltd have developed a CD and tape programme for drivers, called “The Driver Reviver”. It is supposed to be used by drivers when they are fatigued and take a roadside stop. The tape plays “pink noise” for 15 minutes, the functions of which are both to have the driver relax and to block out external sources of noise. A 15-minute nap has been shown to be optimal for drivers to wake up refreshed and better able to continue their journey safely.

There is some evidence that a nap combined with caffeine consumption (preferably taking the coffee first, and then take a nap within 30 minutes) is more beneficial to keep drivers awake than either caffeine or a nap alone (Reyner and Horne, 1997). The nap should not exceed 30 minutes, because longer sleep may produce sleep inertia, from which the driver needs a certain time to recover. Nap areas need to be provided where possible.

There is a clear need for controlled evaluation studies to assess the effects of the fatigue management training (including its various elements) on the accident risk.

Further information about the services of Awake Ltd. can be found on the Internet address www.awakeltd.info.

Copyright © Institute of Transport Economics, 2004

8. FATIGUE IN COMMERCIAL DRIVING: ADDITIONAL ISSUES

Fatigue is obviously an issue of particular concern in long-distance truck driving, due to a combination of long periods at the wheel and irregular working hours. Evidence regarding effects of time behind the wheel and rest periods on driving performance is very important for managing fatigue by regulating the working hours.

8.1 FATIGUE AND VIGILANCE PERFORMANCE

Concerning the effects of sleep deprivation It should be noted that there is a clear dose-response relationship between hours of sleep and performance, as shown e.g. by Balkin et al. (Balkin et al., 2000). They compared the effects of 3, 5, 7 and 9 hours in bed on simulated driving and various other tasks over 7 consecutive days. An interesting finding was even the smallest reduction of sleep resulted in performance decrements, e.g. on a psychomotor vigilance task. For the most severe sleep deprivation condition (3 hours in bed for 7 nights) it was found that performance did not recover to baseline level even after 3 subsequent nights of recovery sleep (8 hours in bed), implying that “full recovery from substantial sleep debt requires recovery sleep of extended duration” (Balkin et al., 2000). The results from that study were used to optimise the parameters of a model for predicting performance on the basis of a person’s sleep debt and circadian rhythm (Sleep/Performance Model – SPM).

Truck drivers’ self-reports indicate that fatigue influences their driving performance, resulting in increasing reaction time, gear shift errors and reduced speed (Williamson, Feyer, Friswell and Sadural, 2001). It is also interesting that professional drivers have been shown to trade speed for accuracy in a cognitive task (Williamson et al., 2001). Although the reduced speed may indicate that the truck drivers develop strategies to cope better with their slow response compared to other drivers, the findings clearly reflect the deteriorating effect of lack of sleep on performance. There is no evidence that it is possible to get used to less than normal sleep, without compromising the driving performance in one way or other.

Several studies have compared the effects of sleep deprivation to those of inebriation by alcohol. Williamson et al. (2001) compared performance on a series of performance tests under different amounts of sleep deprivation or alcohol ingestion, and they concluded that performance equivalent to 0.05 % blood alcohol contents (BAC) occurred at between 17 and 19 hours of sleep deprivation.

Similarly, Fairclough and Graham (1999) found that the effect of one night sleep deprivation on driving performance was similar to that of 0.07 % BAC. An interesting finding, however, was that drivers were more aware of impairment caused by sleep loss than by alcohol, and consequently better able to compensate.

Arnedt et al. (2001) also compared sleep deprivation with alcohol impairment regarding effects on driving behaviour. They found 18.5 hours without sleep to be equivalent to 0.05 %, and 21 hours equivalent to 0.08 % BAC.

Copyright © Institute of Transport Economics, 2004

8.2 POSSIBLE IMPLICATIONS FOR HOURS OF SERVICE REGULATIONS

In the European Economic Area (EEA), the hours of service regulations for heavy-vehicle drivers are based on EEC regulation number 3820/85. According to the regulations a driver is allowed to drive 9 hours daily (with a possibility for two days of 10 hours) during a week. After a maximum of 4.5 hours of driving, a 45-minute rest period is required (alternatively, two or three breaks of at least 15 minutes, totalling at least 45 minutes). When starting driving again after completing the prescribed 45-minute rest, a new maximum of 4.5-hours driving applies, with the same requirement of at least 45 minutes rest. During a 24-hour period a daily rest of minimum 11 consecutive hours is statutory; this can be reduced to 9 hours maximum 3 times during a week (if compensated within the next week). After a maximum of six daily driving periods a weekly rest period of at least 45 hours is required. Some qualifications to these general rules may apply.

Similar regulations are in effect in the USA and Australia.

In the USA the regulations (U. S. Federal Hours of Service) of the hours of driving are similar to the EEA regulations. Ten hours of driving, or 15 hours on duty are allowed, after 8 hours off-duty. Maximum time on duty during a 7-day period is 60 hours (Balkin et al., 2000). For property-carrying drivers the regulations have been changed from January 2004 to allow 11 hours driving after a minimum of 10 hours off-duty.

Australia allows a maximum of 12 hours of driving and 14 hours of work (including driving) during a 24-hour period (Dawson, Feyer, Grander, Hartley, Haworth and Williamson, 2001). Further, a break of minimum 30 minutes is required after 5.5 hours of driving, and one can work for a maximum of 72 hours during any seven-day period. Also here some qualifications to these rules may apply. The hours of service regulations vary somewhat between the different Australian territories.

It has been pointed out (Williamson, Feyer, Friswell and Finlay-Brown, 2000) that there is little scientific evidence for the efficiency of current hours-of-service regulations for the management of driver fatigue. On the basis of performance measurements both during simulated and actual long-distance driving Williamson et al. (2000) concluded that it is possible to increase trip length to about 16 hours without notable deterioration of performance, provided sufficiently long rest periods between the trips. They point out that 6 hours rest is too little, but it is still not clear how long the rest period should be to recover completely after a 16-hour drive. It should be noted, however, that these studies were based on performance on various tests carried out during breaks in the driving, and not directly on driving performance. Apparently these findings are at variance with the results reported in chapter 4 indicating driving performance decrements after four hours of a 6-hour drive. However, the latter study involved continuous driving, whereas in the Willamson et al. (2000) study the drive contained short breaks. Therefore, further evidence is needed to find the performance effects of various combinations of total driving time and breaks during the drive.

Copyright © Institute of Transport Economics, 2004

Drivers often indicate that they would prefer more flexible hours of service regulations (Feyer, Williamson, Jenkin and Higgins, 1993). A possibility to adjust the regulations to personal needs for sleep and rest periods (and when to take them) is wanted. As long as flexibility can be increased without increasing the total workload and/or reduce the total amount of rest and sleep, it would probably be a positive contribution towards better working conditions and safety.

Some authors have tried to set up certain principles based on the research evidence, to be followed when trying to optimise working hours to prevent drivers from falling asleep.

For example, Dawson et al. (2001) have presented the following guidelines:

- Get a minimum of 6 hours sleep per 24-hour period, preferably during the night
- After long periods with less than normal sleep, get two nights recovery sleep
- Avoid night driving as far as possible
- Work hours should not exceed 12-14 hours in one day, or 70 hours during a 7-day period
- Breaks should at lest comprise 10 % of the workday, and there should be a break of at least 15 min every 5 hours.

The suggestion of avoiding night driving is, however, controversial from a total traffic safety point of view. Because of the higher traffic volume during daytime, transferring heavy vehicle traffic from night-time to daytime may increase the number of collisions with other vehicles, and the total effect on safety is consequently uncertain.

Except for the suggested limitation of night driving, the mentioned recommendations seem to accept slightly shorter breaks and longer driving hours than the current hours of service regulations. Until more firm research evidence can be provided, these guidelines should be considered as absolute minimum requirements for rest periods and maximum requirements concerning time of driving.

Copyright © Institute of Transport Economics, 2004

9. IMPLICATIONS, AND RELATIONS TO OTHER PARTS OF IMMORTAL

The presentations and discussions of the fatigue workshop have confirmed once again that fatigue, sleepiness and hypovigilance constitute very important challenges for everyone who is working to improve road safety.

The licensing authorities in co-operation with the medical profession should attend more closely to the issue of sleep-related disorders and their implications for driving. It is important to detect drivers possibly at risk, and to take appropriate precautions in terms of education, advice and treatment regimes, as well as restrictions on licensing in cases with notoriously high risk.

The police and other enforcement authorities need appropriate knowledge and procedures to detect drivers at risk of falling asleep while driving, or whose driving performance falls short of the requirements for alertness and vigilance.

Other safety professionals have a role to play in terms of educating drivers in general about the risks of driving while fatigued or sleepy, how to be aware of the early signs and precursors, and about effective and ineffective countermeasures.

A particular responsibility rests on the transport business and other companies whose employees drive a car during their work. They are in a key position to secure that their employees are properly informed, trained and educated in order to manage the challenge of always staying awake and vigilant while driving a car.

The challenge of the industry is to develop safe and reliable systems for preventing drivers from driving while tired, and/or to restrict the negative consequences of such driving.

The research community has a responsibility to provide better knowledge about the behavioural and physiological mechanisms lying at the base of driver fatigue and sleepiness, including the perception of early signs of hypovigilance, as well as to evaluate the potential of various measures to influence drivers not to drive while fatigued. The problem of appropriate rest breaks is still a partially open question, which needs further studies. The contribution of the vehicle and road environment to hypovigilance needs to be clarified. And the relationship between driving hours and crash risk needs to be further analysed, taking into account both circadian variations, time since sleep, as well as amount and regularity of previous sleep.

The results reported here should be seen in conjunction with other deliverables from the IMMORTAL project. Deliverable D-R1.1[13], a literature study and metaanalysis of relative crash risk associated with various medical conditions (Vaa, 2003), includes risk estimates for sleep-related disorders. Deliverable D-R1.2 (Sagberg, 2003) provides additional risk estimates based on a recent study of health-related symptoms and complaints among crash-involved drivers. Further, there is a plan to

[13] The numbers used for Deliverables and Tasks refer to the Technical Annex of the contract for the IMMORTAL project.

Copyright © Institute of Transport Economics, 2004

address fatigue (and alcohol) as a comparison condition in a driving simulator study of diabetes (Task R1.6).

The efficiency of measures such as licensing restrictions for health problems, including sleep-related disorders, is being assessed by cost benefit analyses in Task P2.

Since the fatigue workshop is a part of the Policy workpackage of IMMORTAL, the present deliverable will serve as an input to the synthesis report from that workpackage.

Copyright © Institute of Transport Economics, 2004

10. SUMMARY AND CONCLUSIONS

On the background of the presentations and discussions in the workshop, the following main conclusions can be drawn.

- A comprehensive research literature provides clear documentation that fatigue and sleepiness are among the most important causes of road traffic accidents. For personal injury accidents most estimates of sleep and fatigue involvement are in the range of 10 to 30 percent of accidents. Fatigue and sleep involvement is especially high for 1) fatal accidents, 2) accidents on rural and/or major roads, 3) accidents with young, male drivers, and 4) truck accidents.
- The most important cause of driver sleepiness is insufficient sleep. Accumulated sleep deprivation for as little as one hour less sleep than normal per night may result in excessive daytime sleepiness. Using driving under the influence of alcohol as reference, the accumulated effect of less than 7 hours on crash risk may be comparable to a BAC of 0.05 %.
- The circadian rhythm is also an important determinant of sleepiness. Irrespective of the amount of previous sleep, people tend to be most sleepy late at night and in the early afternoon.
- The risk of sleep-related crashes is related both to the circadian rhythm, to hours behind the wheel, and to the adequacy of rest breaks during the drive.
- A proportion of drivers have medical disorders resulting in excessive sleepiness. A rather common condition is the obstructive sleep apnoea/hypopnoea syndrome (OSAHS), which affects 4-5 % of the male adult population. Patients with this condition have been shown to have an elevated risk of road accident involvement. The excessive daytime sleepiness can be successfully treated in many of the patients with OSAHS.
- A more serious condition with elevated accident risk, affecting about 1 in 2000 persons, is narcolepsy (or intrinsic sleepiness). Recent research on the neurophysiological and biochemical basis of this disease may contribute to the development of effective medical treatment in the future.
- It is important that the relevant authorities take precautions to secure that individuals with sleep-related disorders are properly assessed before a driver's license is issued or prolonged, at the same time as not discouraging afflicted drivers from seeking treatment.
- Sleepiness and fatigue in drivers can be assessed both by subjective and objective methods. In addition to asking drivers to estimate their sleepiness on various rating scales (subjective methods), one also uses physiological and behavioural indices (objective methods) to investigate relationships of fatigue and sleepiness to driving performance. Much of the knowledge in this field is based on research in driving simulators.
- An important area of research concerns the identification of early signs of sleepiness. Both physiological changes indicating sleepiness, and impaired driving performance may occur before drivers become conscious of their sleepiness. Changes in the EEG (particularly increased power of theta waves) seem to be a sensitive indicator of developing sleepiness. Concerning driving performance, an increased variability in the lateral position is an important early sign.

Copyright © Institute of Transport Economics, 2004

- Eyelid recordings seem to provide useful information to identify various stages in the development of sleepiness. Based on the parameters eyelid opening, blinking frequency, and blinking duration, four different stages in the progression from being awake to falling asleep were identified, which were related to progressively poorer driving performance.
- One line of research identified the time course of various categories of sleepiness precursors and the countermeasures drivers themselves tended to initiate in the various phases. On that basis, implications for operational countermeasures in terms of in-car support, warning, and control systems were formulated.
- Various in car systems for driver monitoring and warning are currently being developed and tested in various projects. Some systems are based on one single parameter of the driver or car, e.g. the head falling forward, eye closure, or abnormal steering wheel movements. Others, e.g., the system being developed in the EU project AWAKE, are based on multiple parameters regarding the driver's state, the vehicle, and the demands from the traffic environment. An important future research need is field trials of such systems in order to assess their effect on driver behaviour and crash risk.
- 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 to much on the safety system. In future research it should be investigated how drivers adapt their driving to such systems, and what operational precautions should be taken to avoid risky behavioural adaptation.
- Drivers are often not motivated to take a break and have a nap when becoming fatigued or tired, but rather tend to engage in several activities in order to keep awake. Research has shown that most such activities (opening the window, increasing the volume of the radio, etc.) at best can postpone sleep for only a few minutes. The only effective countermeasure against sleepiness is sleep, preferably combined with a caffeine drink. A nap of 15 to 30 minutes is very effective and enables a driver to continue driving in an alert and vigilant condition for a considerable period of time. Nap areas need to be provided where possible.
- It is important to increase drivers' awareness of the risks associated with driving when fatigued or sleepy, and about the (in)effectiveness of various countermeasures. The management of companies employing drivers have a special responsibility according to the Occupational Safety and Health legislation to take care that their employees are rested and fit and sufficiently aware of the risks, and also that their working schedules (especially for shiftworkers) are compatible with the needs for rest and sleep. Educational programmes have been developed for helping both companies and individuals to manage fatigue in an adequate way. Concerning warning systems an important message should be that these systems don't reduce sleepiness or fatigue, but they are only backup systems in case the driver is not sufficiently aware of the symptoms.
- It has been assumed that a monotonous road environment may facilitate sleepiness. It is, however, somewhat controversial whether this can occur in sufficiently rested drivers. It may be that monotony and boredom *permit* sleep in a driver who has insufficient sleep, but that it does not *cause* sleepiness. Some preliminary simulator studies of night driving have shown that road lighting has little effect on the development of sleepiness in general, but further research is needed on this issue, to find out to what extent environmental measures can contribute to the prevention of fatigue-related accidents. The idea that monotony

Copyright © Institute of Transport Economics, 2004

and boredom permit sleep also implies on the other hand that stimulation may *mask* sleepiness. Even if one is very sleepy it is not difficult to stay awake while walking around, but once seated comfortably in the car one may fall asleep very quickly.

- Countermeasures against fatigue and sleep-related accidents are of two types. They can either prevent drivers from falling asleep or developing fatigue while driving, or they can alert a driver or intervene with driving once a driver's vigilance is reduced. Thus, there is both primary and secondary prevention of such accidents. Examples of primary prevention are information to raise driver's awareness of early signs of fatigue or sleepiness, or warning systems detecting such signs. In addition, for professional drivers adequate regulations of hours of service are important. Rumble lines along the edge or centre of the road (profiled edgelines/centrelines) is an example of a secondary prevention that has proven very effective. Other examples are the in-car systems to wake up a driver who has fallen asleep.

Copyright © Institute of Transport Economics, 2004

11. LITERATURE REFERENCES

Åkerstedt, T., Fröberg, J.E., Friberg, Y., & Wetterberg, L. (1979) Melatonin excretion, body temperature and subjective arousal during 64 hours of sleep deprivation. *Psychoneuroendocrinology* 4(3), 219-25.

Amundsen, A.H. & Sagberg, F. (2003) Hours of service regulations and the risk of fatigue- and sleep-related road accidents. A literature review. *TØI Report 659/2003*. Oslo: Institute of Transport Economics.

Amundsen, F.H. & Christensen, P. (1986) Countermeasures regarding head-on vehicle accidents - an analysis of accident records. In Norwegian, with summary in English*. TØI Project Report*. Oslo: Institute of Transport Economics.

Arnedt, J.T., Wilde, G.J.S., Munt, P.W. & MacLean, A.W. (2001) How do prolonged wakefulness and alcohol compare in the decrements they produce on a simulated driving task? *Accident Analysis and Prevention* 33(3), 337-344.

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

Arnold, P.K., Hartley, L.R., Corry, A., Hochstadt, D., Penna, F. & Feyer, A.M. (1997) Hours of work, and perceptions of fatigue among truck drivers. *Accident Analysis and Prevention* 29(4), 471-477.

Aserinsky, E. & Kleitman, N. (1953) Regularly occurring periods of eye motility, and concomitant phenomena, during sleep. *Science* 118(3062), 273-274.

Balkin, T., Thome, D., Sing, H., Thomas, M., Redmond, D., Wesensten, N., Williams, J., Hall, S. & Belenky, G. (2000) *Effects of sleep schedules on commercial motor vehicle driver performance.* Report no DOT-MC-00-133. Washington, DC: US Department of Transportation.

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(1), 31-41.

Dawson, D., Feyer, A.M., Grander, P., Hartley, L., Haworth, N. & Williamson, A. (2001) Options for regulatory approach to fatigue in drivers of heavy vehicles in Australia and New Zealand*. Discussion paper from the Fatigue Expert Group* Canberra: National Road Transport Commission.

Dement, W. & Kleitman, N. (1957) The relation of eye movements during sleep to dream activity: an objective method for the study of dreaming. *Journal of Experimental Psychology* 53, 339-346.

Dinges, D., Maislin, G., & van Dongen, H. (2001) Chronic sleep restriction: Relation of sleep structure to daytime sleepiness and performance. *Sleep* 24, A28.

Elvik, R., Mysen, A.B. & Vaa, T. (1997) *Handbook of Traffic Safety Measures*. (Norwegian language.) Oslo: Institute of Transport Economics.

European Transport Safety Council (2001) The role of driver fatigue in commercial road transport crashes*.* Brussels: ETSC

Fairclough, S.H. & Graham, R. (1999) Impairment of driving performance caused by sleep deprivation or alcohol: A comparative study. *Human Factors* 41(1), 118-128.

Fell, D. (1994) Safety update: Problem definition and countermeasure summary: Fatigue*. RUS 5*. New South Wales Road Safety Bureau.

Copyright © Institute of Transport Economics, 2004

Feyer, A.M., Williamson, A.M., Jenkin, R. & Higgins, T. (1993) Strategies to combat fatigue in long distance road transport industry: The bus and coach perspective. *Report CR 122*. Canberra: Australian Department of Transport and Communications.

FMCSA (2000) Hours of service for drivers. Driver rest and sleep for safe operations. *DOT Report 49 CFR*. Washington, DC: Deparment of Transportation.

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

Gårder, P. & Alexander, J. (1995) Fatigue related accidents and continuous shoulder rumble strips (CSRS). *Transportation Research Board 74th Annual Meeting*

Hamelin, P. (1987) Lorry drivers' time habits in work and their involvement in traffic accidents. *Ergonomics* 30(9), 1323-1333.

Haworth, N.L., Heffernan, C.J. & Horne, E.J. (1989) *Fatigue in truck accidents*. Clayton Victoria: Monash University.

Horne, J.A. & Reyner, L.A. (1995) Sleep-related vehicle accidents. *British Medical Journal* 310(6979), 565-567.

Kecklund, G. & Åkerstedt, T. (1995) Time of day and Swedish road accidents. *Shiftwork International Newsletter* 12(1), 31.

Knipling, R.R. & Wang, J.-S. (1995) Revised estimates of the US drowsy driver crash problem size based on general estimates system case reviews. *39th Annual Proceedings*. Association for the Advancement of Automotive Medicine.

Laube, I., Seeger, R., Russi, E.W. & Bloch, K.E. (1998) Accidents related to sleepiness: Review of medical causes and prevention with special reference to Switzerland. *Schweizerische Medizinische Wochenschrift* 128(40), 1487-1499.

Lyznicki, J.M., Doege, T.C., Davis, R.M. & Williams, M.A. (1998) Sleepiness, driving, and motor vehicle crashes. *JAMA-Journal of the American Medical Association* 279(23), 1908-1913.

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 Report No. HS-803 799*. Washington, DC: US Department of Transportation.

Maycock, G. (1997) Sleepiness and driving: The experience of UK car drivers. *Accident Analysis and Prevention* 29(4), 453-462.

McCartt, A.T., Hammer, M.C. & Fuller, S.Z. (1998) Study of fatigue-related driving among long-distance truck drivers in New York State. New York: Institute for Traffic Safety Management and Research.

McCartt, A.T., Ribner, S.A., Pack, A.I. & Hammer, M.C. (1996) The scope and nature of the drowsy driving problem in New York State. *Accident Analysis and Prevention* 28(4), 511-517.

Mitler, M.M., Miller, J.C., Lipsitz, J.J., Walsh, J.K., and Wylie, C.D. (1997) The Sleep of Long-Haul Truck Drivers. *New England Journal of Medicine* 337(11), 755-762.

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), 769-775.

Reyner, L.A. & Horne, J.A. (1997) Suppression of sleepiness in drivers: Combination of caffeine with a short nap. *Psychophysiology* 34(6), 721-725.

Reyner, L.A. & Horne, J.A. (2002) Efficacy of a 'functional energy drink' in counteracting driver sleepiness. *Physiology & Behavior* 75(3), 331-335.

Reznick, R.K. and Folse, J.R. (1987) Effect of sleep deprivation on the performance of surgical residents. *American Journal of Surgery* 154, 520-525.

Copyright © Institute of Transport Economics, 2004

Robilliard, D.L., Archer, S.N., Arendt, J., Lockley, S.W., Hack, L.M., English, J., Leger, D., Smits, M.G., Williams, A., Skene, D.J., and Von Schantz, M. (2002) The 3111 Clock gene polymorphism is not associated with sleep and circadian rhythmicity in phenotypically characterized human subjects. *Journal of Sleep Research* 11, 305-312.

Sagberg, F. (1999) Road accidents caused by drivers falling asleep. *Accident Analysis and Prevention* 31(6), 639-649.

Sagberg, F. (2003) Driver health and crash involvement. A case-control study of relative risk*. IMMORTAL Deliverable D-R1.2*. Oslo: Institute of Transport Economics.

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.

Summala, H. & Mikkola, T. (1994) Fatal accidents among car and truck drivers: Effects of fatigue, age, and alcohol consumption. *Human Factors* 36(2), 315-326.

Taoka, G.T. (1998) Asleep at the wheel: A review of research related to driver fatigue. *Transportation Quarterly* 52(1), 85-92.

Transportation Research and Marketing (1985) A report on determination and evaluation of the role of fatigue in heavy truck accidents*.* Washington, D.C.: AAA Foundation for Traffic Safety.

UK Department of Transport (2002) Sleep-related vehicle accidents on sections of selected trunk roads and motorways in the UK 1995-1998*. Road Safety Research Report 22*.

US National Transportation Safety Board (1990) Safety study. Fatigue, alcohol, other drugs, and medical factors in fatal-to-the-driver heavy truck crashes*. Report NTSB/SS-90/01*.

Vaa, T. (2003) Impairments, diseases, age and their relative risks of accident involvement: Results from meta-analysis*. IMMORTAL Deliverable D-R1.1*. Oslo: Institute of Transport Economics.

Williamson, A., Feyer, A.M., Friswell, R. & Finlay-Brown, S. (2000) Demonstration project for fatigue management programs in the road transport industry: Summary of findings*. Road Safety Research Report CR 192*. Canberra: Australian Transport Safety Bureau.

Williamson, A.M., Feyer, A.M., Friswell, R. & Sadural, S. (2001) Driver fatigue: A survey of professional long distance heavy vehicle drivers in Australia*. Information paper/Report CR 198*. Canberra: Australian Transport Safety Bureau.

Williamson, A.M., Feyer, A.M., Mattick, R.P., Friswell, R. & Finlay-Brown, S. (2001) Developing measures of fatigue using an alcohol comparison to validate the effects of fatigue on performance. *Accident Analysis and Prevention* 33(3), 313-326.

Copyright © Institute of Transport Economics, 2004

APPENDIX 1
WORKSHOP PROGRAMME

Copyright © Institute of Transport Economics, 2004

9.00 – 9.20	Welcome and project concept presentation	Fridulv Sagberg, Institute of Transport Economics (TØI), Gunnar Jenssen, SINTEF
9.20 – 9.50	General introduction to the workshop topics: “Fatigue, sleepiness and driving: Knowns and unknowns”	Fridulv Sagberg, TØI
	Session 1: Causes, indicators, consequences	Chairman: Terje Assum, TØI
9.50 – 10.40	“Sleepiness – its causes and sequelae”	Adrian Williams, St. Thomas’ Hospital, London
10.40 – 11.00	(Coffee break)	
11.00 – 11.45	“Recording drowsy drivers in a simulator”	Alain Muzet, CEPA-CNRS, Strasbourg
11.45 – 12.15	Discussion	
12.15 – 13.15	***Lunch***	
	Session 2: Implications and countermeasures	Chairman: Truls Vaa, TØI
13.15 – 14.00	"Vigilance, fatigue, sleepiness - sensitivity and specifity of eyelid measures"	Hans-Peter Krüger, University of Würzburg
14.00 – 14.50	“The AWAKE project”	Alain Muzet, CEPA-CNRS, Strasbourg
14.50 – 15.10	(Coffee break)	
15.10 – 15.45	"Managing occupational driver fatigue: Raising awareness, reducing risk"	Paul Jackson, Awake Ltd., London
15.45 – 16.15	Discussion	
16.15 – 16.30	***Concluding comments***	Gunnar Jenssen, SINTEF

Copyright © Institute of Transport Economics, 2004

APPENDIX 2

ABSTRACTS OF PRESENTATIONS

Copyright © Institute of Transport Economics, 2004

Fatigue, sleepiness and driving: Knowns and unknowns (General introduction to the workshop)
Fridulv Sagberg, Institute of Transport Economics, Oslo

Falling asleep while driving a car is obviously hazardous. In addition, drivers who are fatigued without actually falling asleep are probably also more likely to be involved in a crash than a rested driver. According to several different estimates more than one out of four drivers have fallen asleep at the wheel at least once in their lifetime. The extent of driving while being impaired by fatigue is more difficult to ascertain. The most frequent consequence of falling asleep is crossing the right edge-line before waking up. Fortunately, only a minority of the incidents result in an accident, most often running off the road, and some times (although less frequent) a frontal crash with another vehicle.

The estimates of the contribution of sleep and fatigue to the number of road crashes vary considerably, due both to under-reporting of these factors by drivers, and due to different methods of investigating the problem. It is generally agreed that sleep and fatigue are among the most important single causal factors of serious traffic crashes. Probably 10% or more of the road fatalities are directly related to sleep or fatigue.

Although the risk of falling asleep while driving is highest during night-time, a large proportion of sleep-related incidents and crashes occur during daytime. There are also indications that drivers may fall asleep even without preceding sleep deprivation. Although persons with sleep disorders are over-represented in sleep related crashes, a large majority of the incidents and crashes occur among healthy drivers. Young male drivers are at higher risk both of falling asleep and of being involved in fatigue-related crashes. A large majority of the crashes occur on rural roads, which implies that crashes related to sleep or fatigue on average are more severe than other crashes, due to high speed and the lack of a braking response.

It is very important to have sound knowledge about the preconditions as well as the immediate circumstances of falling asleep while driving, as well as knowledge about the behavioural and physiological mechanisms involved. A great challenge is to specify relevant indicators of fatigue as well as early warnings of falling asleep, to find out to what extent drivers aware of the signals and pay heed to them. Knowledge of the behavioural aspects of sleep and fatigue is essential in order to predict the efficiency of various countermeasures, which may be focussed on in-car warning systems, road infrastructure and/or driver awareness.

Copyright © Institute of Transport Economics, 2004

Sleepiness – it's causes and sequelae
Adrian J. Williams, St. Thomas Hospital, London

Sleep is not a passive withdrawal from the environment, but an active process consisting of two distinct states, Non Rapid Eye Movement (Non-REM) and Rapid Eye Movement (REM) sleep. Although the underlying mechanisms of sleep are imperfectly understood, certain influences are appreciated, in particular homeostatic and circadian drives. In a former instance, it is appreciated that increasing periods of wakefulness are associated with an increasing propensity to sleep. Whilst in the latter, it is recognised that there is the greatest pressure to sleep at two points in the day, either in the early hours of the morning around 5-6 a.m. or in the middle to late afternoon around 2-5 p.m. Both these drives have an impact on the potential for sleepiness.

Excessive daytime sleepiness is a condition in which the individual feels drowsy during the day and has the urge to fall asleep. People with EDS may doze, nap or fall asleep in situations where they need or want to be fully awake and alert. EDS can interfere significantly with a person's ability to concentrate and perform daily tasks, with resulting negative, economic and public health outcomes, reduced work and school performance, impaired psychological functioning along with workplace and other accidents.

True EDS is rarely, if ever, (contrary to popular opinion) due to a psychological or a psychiatric condition, laziness or boredom. In the absence of <u>insufficient</u> sleep, daytime sleepiness is caused either by sleep <u>interrupted</u> by sleep apnoea, periodic limb movements or a general medical condition such as Parkinson's Disease, or by <u>abnormal CNS regulation</u> of sleep and wakefulness, i.e. narcolepsy and its variants.

One sequelae of excessive sleepiness is the potential for sleep related vehicular accidents. Undemanding and monotonous driving facilitates sleepiness. Each year in the U.S., car crashes involving drivers falling asleep at the wheel exceed 100,000 in number with at least 1500 deaths, while in the U.K. it is believed that 15-20% of motor vehicle accidents, unrelated to alcohol or drugs, are similarly caused by sleepiness. There are clear time-of-day effects with these accidents peaking around 2-6 a.m. and 2-4 p.m. consistent with the previously mentioned circadian peaks of drive to sleep.

A strong association between sleep apnoea and the risk of traffic accidents is now well documented. A Spanish study found that one hundred and two drivers received emergency treatment after road traffic accidents were more likely by a factor of six to have obstructive sleep apnoea. A French study suggests that approximately one half of drivers involving sleep-related accidents have sleep disorders with 31% having clear indications of obstructive sleep apnoea.

Driver-performance can be measured by simulators with varying degrees of sophistication. In some patients with obstructive sleep apnoea performance of sleep apnoeics is worse than in subjects intoxicated with alcohol. Beneficial effects of treatment including CPAP and surgery have been shown using these simulators, underscoring the direct impact that sleep disorders have on the ability to drive.

Copyright © Institute of Transport Economics, 2004

Recording drowsy drivers in a simulator
Alain Muzet, CEPA-CNRS, Strasbourg

Driving simulation is an important research tool for studying potentially dangerous driving situations and/or abnormal driver's state provoked by excessive fatigue or use of drugs and medications. Drowsiness is a physiological state which often occurs in long and monotonous tasks, including driving. Its occurrence and severity depend on several factors such as elapsed time since last sleep period, mental or physical fatigue, time of the day or length of the previous sleep episode. Drowsiness can be detected through physiological measures (EEGs, eyes movements and blinks, autonomic variables,…), behavioural measures (body posture changes, specific attitudes or facial mimics, self-centred movements,…), subjective evaluations or performance data (variations in speed, lateral position, steering wheel movements,…). Detection of occurring drowsiness is important in term of driving safety. Drowsy driver is in danger when facing sudden unexpected situation and this state can be followed by unexpected falling asleep. Therefore, preventing and avoiding occurrence of drowsiness at the wheel constitute a main research goal. Predicting and/or detecting its occurrence in real time is a real challenge. The European project AWAKE constitutes one example of the possible approach of such a difficult task.

Copyright © Institute of Transport Economics, 2004

Vigilance, fatigue, sleepiness – sensitivity and specificity of eyelid measures

Hans-Peter Krüger, Center of Traffic Sciences, University of Würzburg

The measurement of eyelid behaviour is a promising candidate for measuring the energetic state of a driver. A substantially new method is presented where different aspects of eyelid behaviour are combined into one “fatigue index”. Four different states were discriminated: wide awake, reduced vigilance, drowsiness, falling asleep. The validity of the index is proven by concurrent measures of central physiological parameters (EEG), performance measures and subjective reports. Experiments in the driving simulator as well as in real driving were conducted to determine the usability of the index.

In the second part, an attempt is presented to determine the subjective mental model of fatigue and drowsiness. Evidently, subjects are able to identify the symptoms of reduced energetic states. Furthermore, they have developed more or less efficient compensatory strategies. The psychometric evaluation of these subjective reports gives insight into the regulatory processes linked with reduced activation. The results suggest that compensatory regulation is based on the driver’s perceptions of his own performance and his actual energetic state.

Copyright © Institute of Transport Economics, 2004

The AWAKE project
Alain MUZET, CEPA-CNRS, Strasbourg.

The objective of AWAKE is to increase traffic safety by reducing the number and the consequences of traffic accidents caused by driver hypovigilance. In order to achieve this objective, AWAKE intends to develop an unobtrusive, reliable system, which will monitor the driver and the driving environment and will detect in real time hypovigilance, based on multiple parameters. The system will achieve enhanced reliability and minimised false alarm rate, by supporting continuous, instead if discrete, event-related driver monitoring, strong system personalisation to driver characteristics and traffic situation awareness. In case of hypovigilance, the system will provide an adequate warning to the driver, with various levels of warnings, according to the estimated driver's hypovigilance state and also to the estimated level of traffic risk. This system will operate reliably and effectively in all highway scenarios.
More specifically, the objectives of AWAKE are:
- To develop a Hypovigilance Diagnosis Module (HDM), that will detect and diagnose in real-time driver hypovigilance. This system will fuse, via an artificial intelligence algorithm, data from on-board driver monitoring sensors as well as driver's behavioural data. HDM will then be strongly personalised to the driving characteristics of each driver.
- To develop a Traffic Risk Estimation (TRE) module, to assess the risk of the traffic situation. This system will match data from an enhanced navigation map, anti collision radar, speedometer and driver's gaze direction sensor, following a deterministic approach.
- To develop an optimum, modular, on-time Driver Warning System (DWS), using acoustic, visual and haptic means. Various levels of warnings will be considered, according to the risk level estimation and driver's estimated vigilance status.
- To develop a Hierarchical Manager with self-diagnosis capabilities, to co-ordinate all the above subsystems.
- To integrate all the above subsystems and sensors in a single unit (AWAKE unit), appropriate for real-life automotive applications (in terms of cost, dimensions, weight, reliability, robustness, etc.).
- To diversify and adapt the sensors and subsystems to support: a middle and an upper class passenger car and a heavy vehicle demonstrator, in order to cover all relevant application fields.

Copyright © Institute of Transport Economics, 2004

Managing Occupational Fatigue: Raising awareness, reducing risk

Paul Jackson, Awake Ltd.

Awake Ltd is the UK's only private research consultancy dedicated to reducing fatigue related accidents. Awake is linked with Loughborough Sleep Research Centre and works with companies to reduce workplace accidents. We do this by carrying out risk assessments, delivering training programmes and materials designed to raise awareness of the dangers of driving or operating machinery while tired.

Our research has shown that many drivers do not appreciate the danger they are in when driving while tired. Hence our approach begins with raising awareness of the extent of the problem before providing trainees with effective countermeasures that can be put in place in the workplace and at home. This presentation discusses Awake's approach and countermeasures that Awake has developed for clients including BP, Shell, Ford, Procter and Gamble, the UK Police and the UK Department for Transport.

Copyright © Institute of Transport Economics, 2004

Copyright © Institute of Transport Economics, 2004

APPENDIX 3

LIST OF WORKSHOP PARTICIPANTS

Copyright © Institute of Transport Economics, 2004

Werner Klemenjak	KuSS	Austria
Vlasta Rehnová	Transport Research Centre CDV	Chech republic
Jesper Sølund	Danish Road Safety Council	Denmark
Alain Muzet	CNRS-CEPA	France
Hans-Peter Krüger	University of Würzburg	Germany
Ingrid van Schagen	SWOV	Netherlands
Jan Ramaekers	University of Maastricht	Netherlands
Tore Vaaje	Gjensidige NOR Insurance	Norway
Fridulv Sagberg	Institute of Transport Economics	Norway
Susanne Nordbakke	Institute of Transport Economics	Norway
Terje Assum	Institute of Transport Economics	Norway
Torkel Bjørnskau	Institute of Transport Economics	Norway
Truls Vaa	Institute of Transport Economics	Norway
Alf Glad	Norwegian Public Roads Administration	Norway
Jan E. Isachsen	Norwegian Public Roads Administration	Norway
Gunnar D. Jenssen	SINTEF	Norway
Lillian Fjerdingen	SINTEF	Norway
Jardar G. Sæther	University of Trondheim	Norway
Sturla Krekling	University of Trondheim	Norway
Susana Pacheco Calvo	Dirección General de Tráfico	Spain
Javier Alvarez	University of Valladolid	Spain
Alexandra Holmes	Awake Ltd.	UK
Paul Jackson	Awake Ltd.	UK
Philip Dixon	Police Scientific Development Branch	UK
Adrian J. Williams	St. Thomas Hospital, London	UK
Chris Woods	University of Leeds, School of Pscyhology	UK

Copyright © Institute of Transport Economics, 2004