FFI

DROWSY DRIVER

Fordonsstrategisk Forskning och Innovation

Drowsy Driver Project Final Report

Project title: Drowsy Driver, Dnr: 2009-04735

Author: Susanna Leanderson Olsson, Volvo Technology AB

Date: 2012-07-06

FFI in short

FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, of which half is governmental funding. The background to the investment is that development within road transportation and Swedish automotive industry has big impact for growth. FFI will contribute to the following main goals: Reducing the environmental impact of transport, reducing the number killed and injured in traffic and Strengthening international competitiveness. Currently there are five collaboration programs: **Vehicle Development, Transport Efficiency, Vehicle and Traffic Safety, Energy & Environment and Sustainable Production Technology.**

For more information: www.vinnova.se/ffi

Table of contents

About this report

This is the final report of the FFI project Drowsy Driver, conducted within the FFI program *Vehicle- and traffic safety* during the years 2010-2011. The project was a collaboration initiative between AB Volvo, Autoliv, VTI, the Stress Research Institute at Stockholm University (SU), Trafikverket and Chalmers University of Technology (CTH).

This report summarizes the project scope and main results.

Summary in English

Driver fatigue is a huge traffic safety problem and is widely believed to be one of the largest contributors to fatalities and severe injuries in traffic today, either as a direct cause of falling asleep at the wheel or as a contributing factor in lowering the attention and reaction time of a driver in critical situations [2], [3]. Accidents with commercial heavy vehicles are not only dangerous but also very costly and the counteraction of driver fatigue is highly important for improvement of road safety.

Previous research e.g. in the IVSS project DROWSI, finalized in 2009, show the complexity of driver fatigue [4]. On the technical side one of the challenges are the individual differences; how symptoms on drowsiness are shown and the behavior of different drivers when being drowsy. On the non-technical side a challenge is to incorporate routines and processes for managing driver fatigue in the daily operations at road transportation companies, while maintaining cost efficiency and fulfilling delivery constraints and customer demands.

For counteracting driver fatigue on a long term it is of great importance to approach driver fatigue in a multidisciplinary fashion, by combining technical support systems with complementary actions of non-technical character for providing incentives and the right prerequisites for minimizing potential accidents.

The main objective with this project has been to define a Fatigue Risk Management (FRM) program for the commercial road transport area, following the recommendations from the DROWSI project. The work has focused on the development of concept solutions; tools and methods for fatigue risk management and how to work with driver fatigue on a strategic and tactical level.

Another part of the project has been focusing on enhancement techniques of a drowsiness detection system in terms of blink behavior based indicators and increased robustness and availability of a lane position monitoring system by using additional sensor sources.

Finally, a warning strategy in terms of vibrations in the steering wheel has been investigated and evaluated in a driving simulator experiment.

Sammanfattning på svenska

Förartrötthet är ett stort trafiksäkerhetsproblem och troligtvis en av de mest bidragande faktorerna till allvarliga olyckor och dödsfall på våra vägar [2], [3]. Olyckor med tunga fordon är allvarliga ur flera aspekter; tragiska då de ofta leder till allvarliga skador eller dödsfall och kostsamma för både samhälle och företag. Arbete för att motverka föratrtrötthet är därför oerhört viktigt för att förbättra trafiksäkerheten.

Tidigare forskning i tex IVSS projektet DROWSI som avslutades 2009 har tydligt visat på komplexiteten med förartrötthet [4]. En av utmaningarna när det gäller tekniska motåtgärder i form av detektions- och varningssystem är att hantera individuella skillnader i beteende och hur symptom på trötthet yttrar sig hos olika förare. En förares trötthet påverkas inte enbart av dennes sömn- och matvanor, hälsa och andra individuella faktorer, utan även av hur förarens arbete och körningar läggs upp och planeras. En annan utmaning är därför att integrera rutiner och processer för att motverka trötthet i verksamheten hos ett transportföretag, samtidigt som kraven på kostnadseffektivitet och leveransprecision möts.

Förartrötthet behöver därför angripas på flera plan för att kunna motverkas i praktiken. Genom att kombinera tekniska system och stödfunktioner med andra åtgärder, på såväl individuell som organisatorisk nivå, kan man på ett framgångsrikst sätt successivt minska risken för förartrötthet och därmed risken för olyckor som en följd av detta.

Det huvudsakliga målet med projektet har varit att identifiera ett handlingsprogram för trötthetsrelaterade risker; Fatigue Risk Management (FRM) vilket ligger i linje med rekommendationerna från DROWSI projektet. Detta arbete har fokuserats på att ta fram konceptuella lösningar och verktyg för att hantera förartrötthet när det gäller planering och uppföljning.

Projektet har också utrett potentiella tekniska förbättringar för ett trötthetsvarningssystem, dels genom att utvärdera indikatorer baserade på blinkdata från ett kamerasystem, dels genom att se om tillgänglighet och robusthet hos ett kamerasystem för att detektera filposition kan förbättras genom att använda ytterligare sensorkällor.

Avslutningsvis har en del i projektet utvärderat en varningsstrategi baserad på rattvibrationer i ett försök i körsimulator.

Background

The IVSS project DROWSI (2006-2009) had the objective of building competence about the nature of drowsy driving and to develop efficient countermeasures that can support the driver. A profound knowledge platform was built during the project for understanding the complex phenomenon of driver fatigue.

A drowsiness detection system for supporting and warning the driver when becoming drowsy was developed and evaluated. The DROWSI project suggested that for such a technical system to be successful in decreasing the risk of driver fatigue related accidents, supplementary actions and measures are needed. Factors such as driver's motivation and risk awareness as well as incentives and attitude from a company management level directly influence the possibility to benefit from a drowsiness detection system in practice.

In the project Drowsy Driver the research is taken a step further for defining a holistic and comprehensive way of working against driver fatigue, including both technical solutions and complementary actions, as proposed in the DROWSI project.

Objective

The main focus in the Drowsy Driver project has been to define a fatigue risk management (FRM) program for commercial road transports. Specific efforts have been put in developing concepts for scheduling, driver coaching and back-office tools as well as potential improvements and new solutions for a detection and warning system.

The following research questions have been addressed:

<u>FRM concepts:</u>

- What are the included components, and their content, in a FRM program with application within commercial road transports?
- How can a FRM program be defined and implemented with purpose to provide enhanced safety and decreased risk of fatigue related accidents?
- What adaptations are necessary for a FRM program within the road transport sector (compared to aviation)?
- What methods and routines can be used within road transport for stimulating the use and potentially increase the effect of a detection and warning system for driver drowsiness?
- What are the needs and demands from potential users?

- May new tools, methods and routines in a FRM program contribute to enhanced knowledge about driver fatigue and increased acceptance of a drowsiness detection system?
- What tools and functions with respect to scheduling, driver coaching and back-office applications can be used for stimulating the use of, and increase the potential benefit of, a detection and warning system for driver drowsiness?

Driver drowsiness detection and warning strategies:

- Which indicators and merging techniques works for detection of driver drowsiness?
- Does the combination and merging of data from different sensor modalities ("sensor fusion") lead to improved drowsiness detection compared to previously tried combinations within DROWSI?
- How are the calculations affected by the choice of time windows?
  May the availability of the detection system be improved by using of GPS- and map data?
- Are vibrations in terms of stimulation and combination of different types of sensory bodies; Meissner and Pacini a potentially good way of awakening drivers that has fallen asleep?

1. Project scope and budget

1.1. Work packages

The project has been divided in the following work packages and tasks:

Work package 1 – Fatigue risk management (FRM) concepts and tools

- Methods for planning and scheduling
- Driver coaching and back office concepts and tools
- SoA of Fatigue Risk Management and existing routines
- Customer/driver clinic
- Policies, routines and legal aspects
- Design of FRM
- Implementation and evalution of parts of FRM

Work package 2 - modeling and analysis

- Methods/strategies for adaptation of drowsiness detection systems
- Development of blink indicators and merging strategies
- Implementation and evaluation of detection system

Work package 3 – prototype development

- Implementation and evaluation of detection system
- Development of HMI and system prototypes
- System integration
- Development of demonstrator
- Simulator study for evaluation of warning strategy

1.2. Budget and financing

The project financing was made up from financing from Vinnova and from two industrial partners. The budget for the project and the individual partners, including own financing and Vinnova funding is provided in Table 1 - Table 3.

Table 1 Project budget per partner and year

Budget per partner and year (SEK)	2010	2011	Total
AB Volvo	2 107 511	509 189	2 616 700
Autoliv	440 000	229 900	669 900
Stress Research Institute	330 000	170 000	500 000
VTI	60 000	620 000	680 000
Chalmers	560 000	20 000	580 000
Trafikverket	193 400	20 000	213 400
Total project budget	3 692 921	1 571 100	5 260 000

Table 2 Vinnova funding per partner and year

Vinnova funding (SEK)	2010	2011	Total
AB Volvo	432 263	104 437	536 700
Autoliv	78 752	41 148	119 900
Stress Research Institute	330 000	170 000	500 000
VTI	60 000	620 000	680 000
Chalmers	560 000	20 000	580 000
Trafikverket	193 400	20 000	213 400
Total funding	1 654 415	975 585	2 630 000

Table 3 Total project budget

Total project budget (SEK)	Financing	Funding	Total
AB Volvo	2 080 000	536 700	2 616 700
Autoliv	550 000	119 900	669 900
Stress Research Institute		500 000	500 000
VTI		680 000	680 000
Chalmers		580 000	580 000
Trafikverket		213 400	213 400
Total	2 630 000	2 630 000	5260 000

2. Results

2.1. WP 1 - Fatigue Risk Management

A SoA survey was conducted to identify current action plans to counteract fatigue related problems at work within different areas such as the aviation industry, and to provide recommendations for the design of a FRM program for commercial road transports [5].

A well thought-out system specifically developed for handling and preventing driver fatigue will imply positive effects not only for the individual co-worker but also for the whole company. A FRM program is an example on a structured way of working to address the problem. To serve its purpose the introduction of a FRM program should be well-founded, in demand and supported by management. Education of the intended users (drivers and other actors e.g. back-office staff), scheduling, routines and documentation are the most important components for a successful work plan.

A typical program for handling fatigue related risks is designed in several steps, applied in different phases and involves different levels of the organisation. In what way an organisation choose to define a FRM program depend on the targeted group of people the program is developed for. However, based on a survey of existing programs for handling fatigue related risks in different work areas, a set of key items can be concluded to be of central importance:

- Scheduling and planning tools
- Fitness for duty (fit-for-duty) management
- Health
- Work environment
- Education
- Policy and routines

Based on these key elements, a FRM design for road transport was proposed by the project.

2.1.1. Design of FRM for commercial road transports

The FRM program proposed for commercial road transports is based on four key elements which all contribute in different ways to the overall goal of reducing driver fatigue according to Figure 1, [6]:

- Operation and driver support
- Planning and follow up routines
- Preventive work and education
- Values awareness and competence

On top of these four cornerstones comes the legal aspect which may be a factor that stimulate, and simplify, the possibility to implement this program in practice.

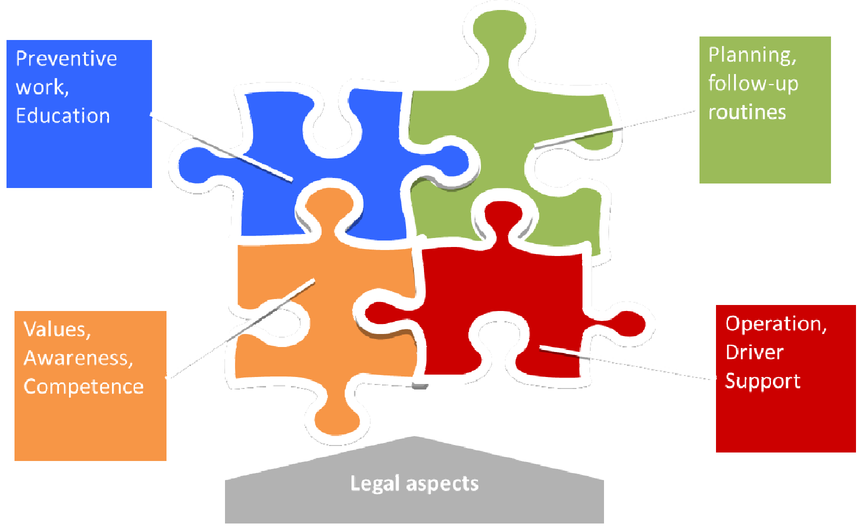

Figure 1 A proposed FRM design for commercial road transport

Previous studies have shown that a way of reducing the risk of drowsiness related traffic accidents is to create good prerequisites for the driver before and during the drive [7], [8]. The human need for rest and sleep found the basis for the model proposed on how to create a set of "protective layers" for reducing the risk of driver fatigue. Good prerequisites are defined by:

1. forming good schedules
    a. regulation of working hours
2. using possibility for sleep
    a. show up rested at work
3. detect drowsiness related symptoms or behaviours by
    a. increasing awareness of typical symptoms
    b. using a technical system in the truck that detects drowsiness
4. warn/intervene in case the driver is tired
    a. create a culture allowing drivers to tell before a driving session that they are tired.
    b. integrate a warning system in the truck

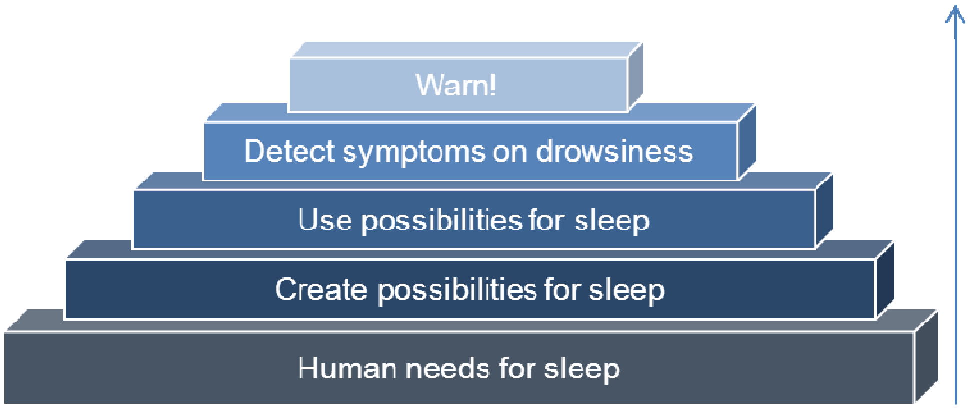

Figure 2 Model for stepwise handling of drowsiness related risks

The FRM concept suggested by Drowsy Driver is presented Figure 3. It is founded on a model developed by Dawson and Fletcher (2001) where the risk for an accident is minimised by of a set of protective "layers" with various support functions to prevent and / or mitigate incidents caused by fatigue [9]. This principle could be referred to as fatigue proofing, which should be interpreted as a structured way of working to reduce the risk of fatigue related accidents. Each layer contains a number of support functions with different content and meaning, involving different parts of the organisation and used in different phases of the daily operation.

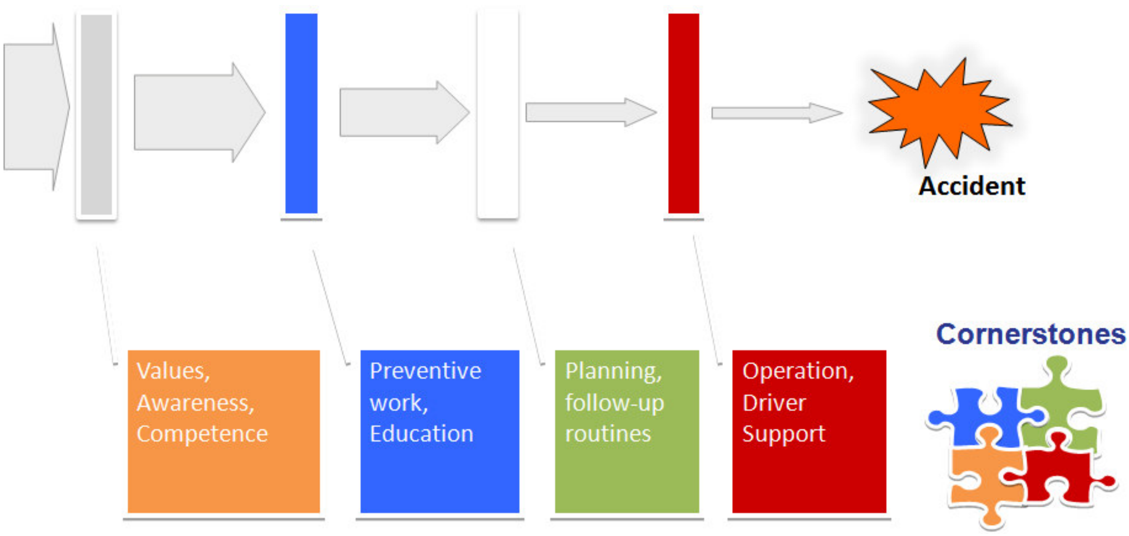

Figure 3 Fatigue risk prevention by protective layers

The protective layers; FRM corner stones, each provide an important part of the chain for reducing the risk for fatigue related accidents. On a strategic level, the work is founded on the corporate values of the company which in turn are reflected in policies and processes which are followed in the daily work.

On the tactical level methods and tools are used for planning and follow- up and on the operational level, driver coaching and back-office functions are used during the drives as support for preventing on-road incidents.

The design and implementation of the FRM is illustrated in Figure 4, where the value base is the core and represented by routines for prevention, planning, operation and follow-up in various phases and different parts of the operation.

Figure 4 Implementation of FRM; process flow

2.1.2. Prevention - values, awareness and competence

The awareness and motivation of the drivers and the proposed routines and communication from management level is believed to play an important role in the efforts of minimizing the risk of fatigue-related accidents involving commercial vehicles for creating long term behavioral changes.

These corporate values founds the basis for the company culture and are highly important for the recognition of driver fatigue as an important problem and for providing the support from management level on the need for counteracting the problem. Education for increasing the awareness and competence of all the involved actors are important steps and parts of the preventive work for creating a common understanding and acceptance.

Policies are important for describing and establishing objectives, routines and requirements. These needs to be formulated individually for each organisation to consider the unique presrequisites.

2.1.3. Mathematical models

There are strong indications that mathematical alertness models are of great value for providing schedules that consider the risk of fatigue related accidents [10], [11]. Such models can also be valuable as input to the drivers, in order to predict when there is a high risk for drowsiness and for planning breaks and naps along the road.

Alertness models can also be used for training purpose, to educate staff in management of fatigue. An alertness model needs to be adjustable to individual differences in terms of need of sleep, circadian rhythm and sensitivity for sleep loss to be an optimal support on the individual level, for example how to plan for sleep to avoid serious lack of sleep.

In the Drowsy Driver project, alertness models have been used in the development of a scheduling algorithm and in the driver coaching and back-office solutions.

2.1.4. Planning – scheduling algorithm

In the aviation industry there are since a long time established ways of working with scheduling methods where critical factors like time of day and biological mechanisms are considered. The application of scheduling methods for road transports adds complexity due to an increased number of possible choices with respect to e.g. start and end points and route choices.

In the project an algorithm was developed for producing optimized driving schedules in order to manage driver fatigue for road transports [12]. The work focused on the solution of a classical optimization problem called the vehicle routing problem (VRP). The alertness prediction model; sleep-wake-predictor (SWP) was used for identifying high risk periods and incorporated in the algorithm to produce optimized schedules based on predicted alertness [12], [13]. The problem that needed to be solved was a so called multi objective optimization problem since more than one objective would be fulfilled; while trying to minimize the number of drivers and the total traveled distance, the high risk periods (based on the SWP) was the top priority in making the schedules in the developed algorithm.

Alertness based optimization improved the average driving alertness by 4% and also decreased the duration of high accident risk intervals by 9%. However, as a consequence, the total travelled distance increased with 22%. To be able to apply a similar algorithm in real life a cost benefit analysis of the consequences needs to be performed.

2.1.5. Operation and follow-up - support functions

The support functions proposed in Drowsy Driver was intended as tools for the driver and operator (e.g. transport planner/leader) and consists of tools used for planning and follow-up before and after the trip (off-board) and tools for driver coaching and back-office support during the drive (on-board). A mapping of driver coaching and back-office support functions to the FRM process flow is illustrated in **Figure 5**.

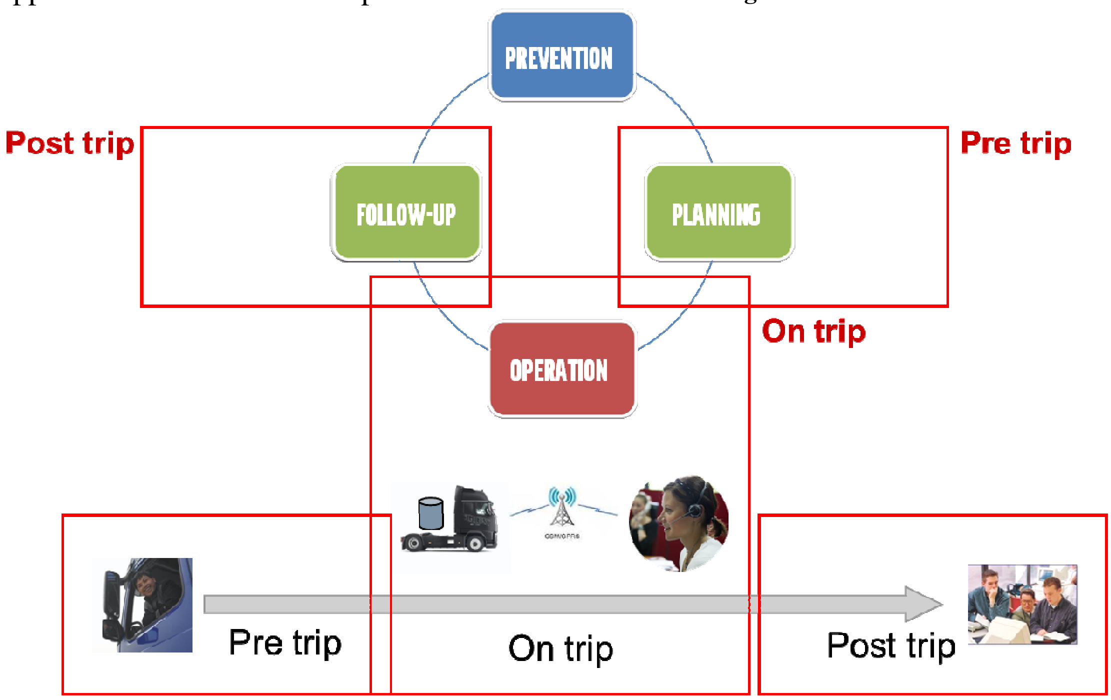

Figure 5 Implementation of operator support functions

By connecting the driver and the vehicle to a back-office via a telematics link an information exchange can be made during the drive such as communication when a drowsiness warning occurs followed by support or advice to the driver from the back-office.

A set of concepts for driver coaching support before, during and after the trip has been developed and implemented of which a few of them is described below. Further details can be found in the project deliverable on driver coaching and back-office concepts [14].

Pre-trip support is represented by a Fit-For-Duty (FFD) function. The FFD is used for checking if the driver is s capable of doing his/her work in a safe way before a driving task, based on the alertness prediction model (SWP).

When a drowsiness warning is issued to the driver, it is also transmitted to a back-office and an operator can support the driver with an appropriate action. Time and position of potential drowsiness warnings are logged together with information about breaks and their time and position at the back-office. This information can be used after and between drives for analysis and initiation of changes in schedules or routes.

A HMI snapshot of the back-office tool implemented in Drowsy Driver for on-trip support is presented in Figure 6.

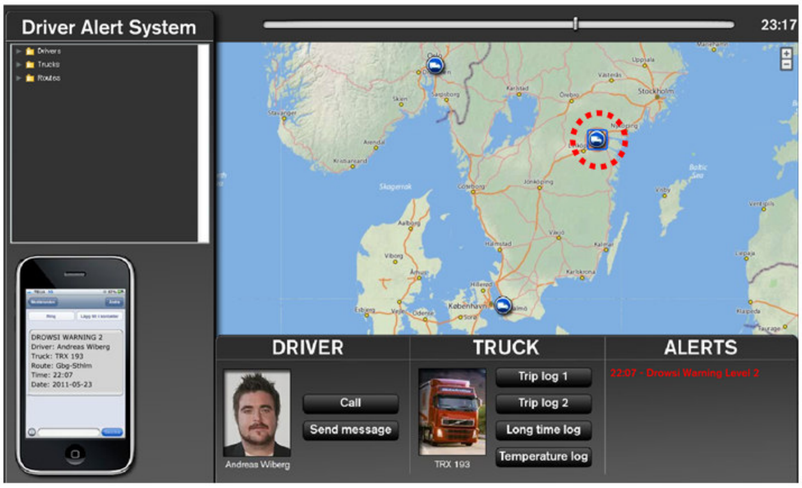

Figure 6 Example of back-office view when drowsiness warning is issued

After the trip the driver can receive a summary of the drive, for example with respect to number of warnings from the detection system, level of warnings, time and position for the warnings, drive and rest time information together with support and advice for minimizing risks for fatigue. The information can be shown in the instrument cluster, by a command from the driver or be available via sms or on the company intranet.

The back-office compiles reports for drivers, specific routes and vehicles. Based on these reports the transport leader can follow-up and work pro-actively together with the driver and create a work plan for future assignments and drives to avoid driver fatigue.

A HMI snapshot of the back-office tool implemented in the Drowsy Driver project for making a post-trip summary is presented in Figure 7.

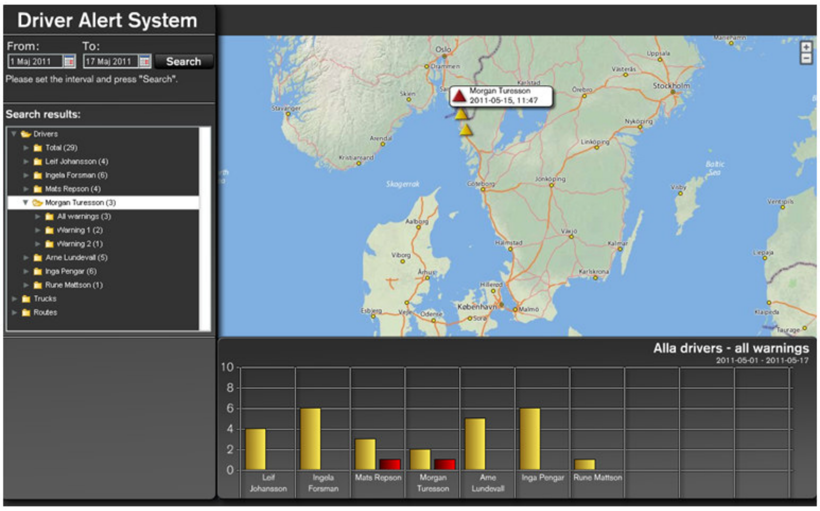

Figure 7 Example of back-office view with post-trip summary of warnings on group level

2.1.6. Analysis and evaluation of FRM

Stakeholder feedback

Interviews with different actors from a set of transportation companies were made in order to achieve feedback on the FRM design and the concepts developed [15]. The scope of the study was relatively small and can therefore not be concluded as representative for drivers and transportation companies in general. However, the results indicate how a FRM program could be perceived by the intended users.

The interview results confirm that driver fatigue should be addressed on an overall level; the work of developing an FRM program is thus in line with the results from the study.

I order for the FRM system to be successfully integrated and used, the objectives and benefits should be clearly communicated so that a common understanding of the work is reached and that all actors involved are committed to the work and procedures.

The incentives and motivation for accepting the routines in a FRM program need to be considered from different perspectives. From the driver perspective the improvements in working conditions as a result of the used processes are essential. It is of importance to handle concerns about “surveillance” and to carefully use personal data as part of the planning and follow-up processes to get acceptance. A fatigue related action plan directed to drivers that include judgment and analysis of driver’s ability to drive safely and/or guidelines that involves the use of the spare time (e.g. need for sufficient sleep) needs to be evaluated with respect to ethical aspects.

In order for a FRM system to be attractive on a company level perspective the benefits of the program needs to be clear. The ability to communicate a safety focus should be valuable for strengthening competitiveness in certain customer segments. Also the FRM system and its contribution to profitability are essential [16]. If the FRM system can contribute to that accidents are avoided, that route planning gets more effective and that driver health in terms of sleep and rest is satisfactory this will contribute in making a FRM system attractive for companies.

A problem might be to convince companies to make investments of new technical systems and to develop procedures for integrating them in the daily operations. Large companies may have resources to support an implementation of a FRM program and the investment of various technical solutions. It may be more difficult for smaller companies to organize this in an efficient way, it is therefore of importance that the design of the FRM systems is appropriate for the size and operation of the company in question.

Business models

For understanding in what way a FRM system could be integrated and packaged to attract transportation companies a number of concepts in the area of drowsy driver detection and prevention and their business potential was investigated.

The investigation showed that "driver-driven" solutions, meaning solutions where data becomes personal for the driver, had the best potential to get accepted and used on the market. With this solution the driver becomes the owner of the data for creating personal track records of driving events and patterns [17]. A challenge is that drivers are not normally in charge of the funds or the purchase decisions. However, this does not necessarily mean that they are not a source of power in the decision process.

2.2. WP2 - Analysis of blink behavior based indicators

The main research aim in this task was to devise improved indicators and systems of indicators based on the eyelid movement signals obtained from camera systems and was included in the final work for a dissertation on driver sleepiness detection that was started in the DROWSI project [18], [19]. The analyses were also carried out with consideration to the previous work on driver sleepiness detection (based on blink behavior) that had been done within the DROWSI project.

2.2.1. Data

The data was collected in the field study of sleepiness in truck drivers which was carried out within the DROWSI project in 2008. The study included two driving sessions for each of the 10 test subjects that participated in the study. In each session the test subject started to drive in Linköping and drove along Riksväg 34 to the town of Målilla where he or she turned around and drove back to Linköping. On average a driving session lasted for about 4 hours.

A range of signals were recorded in the study. In the analyses presented here, however, only the eyelid movement signals recorded with the Driver State Sensor (DSS) camera system have been considered. The DSS was a mono camera system that recorded the following signals at 60 Hz: (1) Left eye closure, (2) Right eye closure, (3) Left eye closure confidence, (4) Right eye closure confidence, (5) Head pose (x,y,z) and (6) Head rotation (x,y,z).

Given the small number of test subjects in the data, no attempt was made in the analyses presented here to study inter-individual differences. Data were divided into segments of 60 seconds, where each such segment is referred to as a *sample* hereafter. Each sample was defined as either sleepy or alert based on Karolinska Sleepiness Scale (KSS).

The classification framework involved decision trees in the form of a sequence of if-then rules. The rules (choice of features, parameters etc.) were determined using an evolutionary algorithms, capable of handling decision trees of varying size. If no rule is satisfied, the sample in question is classified as undetermined. Furthermore, multiclass classification was used. The three classes were *sleepy, alert* and *undetermined*. The idea was to include measures based on the confidence signals in order to allow for the system to give no sleepy/alert classification in the case of high uncertainty regarding a sample.

2.2.2.Results and discussion

A broad range of different kinds of rules were considered, including (1) averages, (2) variances, (3) fraction of signal below threshold, (4) fraction of signal in a certain range, (5) maximum signal value, (6) minimum signal value etc. etc. The best classifier obtained had a performance of:

Training fitness: 0.64478
Validation fitness: 0.49380
Test fitness: 0.47431

In comparison to the best performing indicators from the DROWSI project; the SWP (0.84) and Generic Variability Index (GVI) (0.80) based on deviation in lateral position, an increase of performance could not be concluded from the evaluation of the blink behavior data sets available [19]. However; the results are highly dependent on the hardware and software used in the DSS. Any change to this would likely result in a change in the signals used as input to the classifier.

2.3. WP2 - Enhancement techniques for the lane position system

In the DROWSI project, a drowsiness detection system based on data from a lane position monitoring system was designed and evaluated.

This task was performed as a master thesis work and aimed at investigating if the performance, availability and robustness of such a lane position monitoring system, can be improved using other sensor sources such as GPS, vehicle sensors and environmental perception.

2.3.1. Method

The main concept for the enhancement technique is to use GPS in combination with dead reckoning and map data with applications, making it possible to fetch information about inclination, curvature, lane width and number of lanes. All road attributes, in combination with vehicle sensor information (steering wheel angle, the longitudinal velocity and yaw rate) are used to create a road and vehicle model. The GPS coordinate connected to all sample points gives the possibility to calculate global heading and velocity.

The single most important output from the model for the drowsiness detection perspective is the lane position. This output could be used as information on the lane position if the lane position monitoring system for some reason looses tracking or lane markings are not available on the road.

2.3.2. Data

In order to evaluate the proposed enhancement technique, real data have been collected on a road section where the project have access to an accurate reference used as baseline. The data is divided into two parts, one to tune on and one to evaluate with. The main target is to increase the availability and robustness of the system with the model compared with the lane tracker information, which is based only on the lane markings.

2.3.3. Results

In time for writing this report, the report on the work made within the project is still under finalization.

2.4. WP2 - Prototype development and evalution of warning strategy

In this task a patented method for warning and waking up a driver who has fallen asleep was evaluated, [20]. The warning technique consists of a combination of vibrations in the steering wheel, [21].

In order to avoid critical situations and to have time enough to convince the driver to stop driving it seems reasonable to look at *sleepy drivers* instead of those that already have *fallen asleep.* However, as a fall back it may also be relevant to have a final warning when the driver falls asleep. The idea is to stimulate two different types of sensory bodies, Meissner and Pacini, in the palms and fingers.

The experiment aimed at comparing three different ways of warning:

- Single frequency vibration in the steering wheel
- Vibsec vibrations in the steering wheel
- Seat belt jerks

2.4.1. Method

The study was done in the VTI moving based driving simulator using 12 participants. The simulator scenario consisted of an approximately 40 km long motorway that was looped 2.5 times, resulting in a 93 km test route that took about 50 minutes to drive. The drivers reported KSS when every five minutes, in addition physiological signals were recorded (EEG, EOG, EMG, ECG and respiration. EEG and EOG was scored into Karolinska Drowsiness Score (KDS) that is a method that classifies polysomnographic data according to the presence of alpha or theta activity and slow eye movements.

2.4.2.Results and discussion

The results indicate that there are no major differences in effects between the different types of vibrations. This holds true both for direct effects and long-time effects.

All three vibrations woke up the driver in time for him/her to make correction in order to stay in the lane. The result is in line with the effect of for example rumble strips, use of radio or opening a window. The driver will wake up, but very soon he/she will be back to the same critical situations as before the vibrations was sent. All three vibrations only had a short time effect and after only a couple of minutes the drivers were back to the same behaviour as just before receiving the warning. The drivers' opinions about the vibrations were in overall positive, but the interpretation of the results should be done carefully since there were too few respondents.

In conclusion there are different ways of alerting drivers that has fallen asleep. The results from this study show that the different initiative tested here is only useful for a very short time.

3. Conclusions and recommendations

3.1. FRM design

Systematic management of driver fatigue is believed to have large potential within road transport to increase traffic safety and save money. The methodology has been used in other transport areas (e.g. aviation) for some time and transfer and adaptation of similar solutions for road transports is the next step.

A design of FRM system for commercial road transports and a number of concepts for the included core elements have been defined such as scheduling algorithms and driver coaching and back-office solutions. The use of mathematical models for predicting alertness show potential both for scheduling and educational purposes.

It is essential that all involved stakeholders have a common understanding of the problem and consequences of driver fatigue to get acceptance of the FRM model.

While there is a strong evidence base supporting the principles of FRM systems practical experience of such programs is limited. Recommendations for future work are therefore to integrate and evaluate the proposed FRM system in real life in collaboration with various potential users. Also a better understanding on how authorities could stimulate the development and usage of FRM would be useful. A potential first step might be specific consideration or constraints for special transports; long vehicles or transportation of dangerous goods.

3.2. Detection system; blink indicator evaluation

The results from the blink indicator development and analysis could not be concluded to increase the performance, as a single indicator, compared to other indicators developed within DROWSI. However, the development and evaluation of blink indicators are highly dependent on the hardware and software used in the camera sensor. As sensor techniques improves indicators based on blink behavior, as proposed in this project, might have great potential for increasing the robustness of drowsiness detection systems both as single indicators and in fusion with others.

3.3. Warning strategy for drivers that has fallen asleep

The results of the study showed no major differences in effects between the different types of vibrations. All three vibrations woke up the driver in time for him/her to make correction in order to stay in the lane but the results indicated also that very soon the driver will be back to the same critical situations as before the vibrations was sent. Thus the results from the study show that the different initiative tested here is only useful for a very short time.

4. Participating parties

Partner	Logotype	Contact person	Contact details
AB Volvo	VOLVO	Susanna Leanderson Olsson	susanna.leanderson.olsson@volvo.com
Autoliv	Autoliv	Johan Karlsson	Johan.G.Karlsson@autoliv.com
VTI	vti	Anna Anund	anna.anund@vti.se

Partner	**Logotype**	**Contact person**	**Contact details**
Stress Research Institute	Stockholms universitet	Torbjörn Åkerstedt	torbjorn.akerstedt@stressforskning.su.se
Trafikverket	TRAFIKVERKET	Ruggero Ceci	ruggero.ceci@trafikverket.se
Chalmers University of Technology	CHALMERS	Mattias Wahde	mattias.wahde@chalmers.se

5. Deliverables

Drowsy Driver Deliverables
Semitcheva, A., Ceci, R., Nulägesanalys av hantering av trötthetsrelaterade risker: koncept och verktyg, FFI Drowsy Driver deliverable D1.1, 2010.
Karlsson, A-S., Kronberg, P., Leanderson Olsson, S., Söderman, M., Koncept för driver coaching- och operatörsverktyg, FFI Drowsy Driver deliverable D1.2, 2010.
Kecklund, G., Åkerstedt, T., Rekommendation av schemaläggning som en del av Fatigue Risk Management (FRM), FFI Drowsy Driver deliverable D1.3, 2012
Karlsson, A-S., Söderman, M., Kronberg, P., Design av fatigue risk management lösning, FFI Drowsy Driver deliverable D1.6, 2011
Sardareh, R., Specification and development of scheduling algorithms for managing driver fatigue within road transport, Master Thesis Report and FFI Drowsy Driver deliverable, 2012
Karlsson, A-S., Söderman, M., Behovs- och kravanalys av back-office och driver coaching koncept, FFI Drowsy Driver deliverable D1.4, 2010.
Trafikverket, Driver Alert - Aspekter på introducering av ett trötthetsvarningssystem, FFI Drowsy Driver internal document, 2012
Grante, C., Kronberg, P., Stamlin, R., Drowsy business – potential service offers with Customer Desirability, Technological and Organizational Feasibility, and Business Viability qualities, FFI Drowsy Driver internal document 2012

Drowsy Driver Deliverables
Sandberg, D., Wahde, M., Analysis and optimization of blink behavior based indicators for the detection of driver sleepiness, Chalmers University of Technology, FFI Drowsy Driver internal document 2012-05-28
Anund, A., Evaluation of specific vibrations in steering wheel (Vibsec) as a countermeasure for driver falling asleep - a simulator experiment, FFI Drowsy Driver internal document 2012

References

[1] The FFI program, www.vinnova.se/ffi

[2] Åkerstedt, T. (2000). Consensus statement: fatigue and accidents in transport operations. Journal of Sleep Research, 9 4), 395-395.

[3] Stutts, J. C., Wilkins, J. W. and Vaughn, B. V. (1999). Why do people have drowsy driving crashes? Input from drivers who just dit (No. 202/638-5944). Washington, D.C.: AAA Foundation for Traffic Safety

[4] Kronberg, P. (2010). DROWSI Project Final Report. AL80 A 2005:11065.

[5] Semitcheva, A., Ceci, R., Nulägesanalys av hantering av trötthetsrelaterade risker: koncept och verktyg, FFI Drowsy Driver deliverable D1.1, 2010.

[6] Karlsson, A-S., Söderman, M., Kronberg, P., Design av fatigue risk management lösning, FFI Drowsy Driver deliverable D1.6, 2011

[7] Anund, A. and Patten, C. (2010), *Trötthet vid ratten*, VTI rapport 688

[8] Dawson, D., McCulloch, K., Managing Fatigue: It´s about sleep – stupid

[9] Dawson, D. and A. Fletcher, A quantitative model of work-related fatigue: background and definition. Ergonomics, 2001.

[10] Kecklund, G., Ingre, M. & Åkerstedt, T. 2010. *Arbetstider, hälsa och säkerhet – en uppdatering av aktuell forskning*. Stockholm 2010.

[11] Kecklund, G., Åkerstedt, T., Rekommendation av schemaläggning som en del av Fatigue Risk Management (FRM), FFI Drowsy Driver deliverable D1.3, 2012

[12] Sardareh, R., Specification and development of scheduling algorithms for managing driver fatigue within road transport, Master Thesis Report and FFI Drowsy Driver deliverable, 2012

[13] Kecklund, G., Åkerstedt, T., Sandberg, D., Wahde, M., Dukic, T., Anund, A., Hjämdahl, M. DROWSI State of the art review of driver sleepiness (2007).

[14] Karlsson, A-S., Kronberg, P., Leanderson Olsson, S., Söderman, M., Koncept för driver coaching- och operatörsverktyg, FFI Drowsy Driver deliverable D1.2, 2010.

[15] Karlsson, A-S., Söderman, M., Behovs- och kravanalys av back-office och driver coaching koncept, FFI Drowsy Driver deliverable D1.4, 2010.

[16] Trafikverket, Driver Alert - Aspekter på introducering av ett trötthetsvarningssystem, FFI Drowsy Driver internal document, 2012

[17] Grante, C., Kronberg, P., Stamlin, R., Drowsy business – potential service offers with Customer Desirability, Technological and Organizational Feasibility, and Business Viability qualities, FFI Drowsy Driver internal document 2012

[18] Sandberg, D., Wahde, M., Analysis and optimization of blink behavior based indicators for the detection of driver sleepiness, Chalmers University of Technology, FFI Drowsy Driver internal document 2012-05-28

[19] Sandberg, D., *Detecting Driver Sleepiness*, Doctors dissertation thesis, Chalmers University of Technology, ISSN 0346-718X; nr 0346, 2011

[20] Anund, A., Evaluation of specific vibrations in steering wheel (Vibsec) as a countermeasure for driver falling asleep - a simulator experiment, FFI Drowsy Driver internal document 2012

[21] VibSec patent WO2007/136338