



Rail Safety & Standards Board

Research Programme

Human Performance

Driver vigilance devices: systems review



Rail Safety and Standards Board's (RSSB) response to the report by Quintec entitled 'Driver vigilance devices: systems review'

1. Purpose

- 1.1. The purpose of this paper is to outline RSSB's response to the attached report, and to summarise the actions being taken by RSSB.

2. Background

- 2.1. Driver vigilance devices (DVDs) have been developed by manufacturers in the USA, the UK, and elsewhere for applications in a range of transportation modes. A Russian device, the engine driver vigilance telematic control system (EDVTCS), has been under development for some time and is now widely used on Russian railways. Such devices monitor various physiological measures (as described in the report) to indicate the driver's state of alertness.
- 2.2. As a result of the UK railway industry being approached by the developers of the EDVTCS device, RSSB commissioned a research study, resulting in this report with the aim that industry could be informed about the various physiological measurements that could be taken, their reliability and validity as indicators of alertness, as well as the types of devices that are currently available.
- 2.3. The report was commissioned as part of the Rail Safety Research Programme (RSRP) (now Rail Safety and Standards Board) and was prepared by Quintec. The research comprised a comprehensive and systematic search for vigilance devices, an assessment of the acceptability criteria for their use by train drivers, and an initial cost/benefit estimate.

3. RSSB response

- 3.1 The report provides a valuable overview of the subject and enables readers across the railway industry to be better informed about what measurements are valid when trying to assess alertness.
- 3.2 RSSB do not intend to mandate the introduction of driver vigilance devices, such as the 13 types investigated, in the foreseeable future, if at all. Train operating companies (TOCs) need take no action to introduce such devices for the present.
- 3.3 However, RSSB is supportive of further research and testing of the devices and will keep itself informed about developments in this field.
- 3.4 The first task is for RSSB to obtain the leading device available – the Russian developed EDVTCS - and to conduct tests (in a laboratory setting) to validate the main claims made by the manufacturers.
- 3.5 It is accepted that the timescale for full acceptance and initial introduction of DVDs is likely to take several years. While future technological advances may mean they become increasingly compact, reliable and inexpensive, the

trend towards improved train protection may reduce the need for driver vigilance devices (see report para 6.4).

- 3.6 The findings of the report on the range of physiological measurements considered and the three groups of criteria that the devices need to meet are particularly noteworthy.
- 3.7 RSSB wishes to encourage suppliers, *ie* those who design, develop and manufacture these devices to continue to develop and offer products with eventual railway applications in mind. The 13 suppliers listed in the report are being provided with copies of the report.
- 3.8 The TOCs are of course being given the report and are requested to inform RSSB of their reactions. Their feedback will be of value in determining the scope of future trials and research.

4. Response to specific report recommendations

The recommendations shown in italics below have been paraphrased from the report. Readers may refer to the full wording in the report.

- 4.1 Recommendations 1 - 4: *An estimate/assessment should be made of:*

- a. *the cost of retrofitting devices to cabs*
- b. *the incidence of drowsiness related signals passed at danger (SPADs)*
- c. *cost/benefits for different route categories and TOCs*
- d. *the extent and cost of the full assurance process for device implementation*

to derive an estimate of the potential cost/benefit of fitting DVDs.

Response. It is noted that the process of testing, trials and approvals is likely to be lengthy and the outcome uncertain. These estimates and assessments should be made following item 4.3 (see below). It should be assumed that the first applications would be in new rolling stock, or in conjunction with a major cab refit, rather than a retrofit to existing stock.

- 4.2 Recommendation 5: *Assess whether the current Railway Group Standard (RGS) for vigilance devices would be appropriate for a monitoring device:*

Response. The standard GM/RT2185 defines in section B4.2 the present requirements for monitoring driver alertness and for response to driver incapacity. It does not need to be changed now. If and when advanced trials of DVDs are being conducted, there would be an opportunity to review the standard in the context of technological advances and the devices becoming available.

- 4.3 Recommendation 6 – 10: *If RSSB decide to promote the introduction of the EDVTCS (or another particular type of device), they should:*

- a. *make a further evaluation of the device in current use by others*
- b. *purchase the device for use in a laboratory or simulator*

- c. *establish a benchmark for arousal/alertness*
- d. *investigate the electro-magnetic current (EMC) properties and assess whether rolling stock or signalling systems would be affected by the device*
- e. *assess the user acceptance and railway context issues in the report.*

Response: As described in 3.3 above, this is the next stage of activity. The work should be performed in a laboratory or simulator context.

- 4.4 Recommendation 11. *RSSB should research human error cause categories for the Risk Profile Bulletin (RPB) using fault tree analysis, SPAD data and general human reliability data.*

Response: Research is currently being conducted in the related areas of fatigue, shift work, and sleep deprivation. The Risk Team will continue to gather and make available information in these areas and to assess the incidence of drowsiness as a cause of incidents.

- 4.5 Recommendation 12 *RSSB should research how indicators of visual attention such as gaze direction and fixation time can be used to determine incidence of driver distraction.*

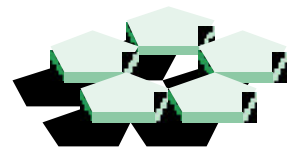
Response: This is already under way in the *Train driver visual strategies* research project.

5 Conclusions

- 5.1 Further work in this area will be considered during the forthcoming months and weighed against competing demands for future research funding.

6 Contact

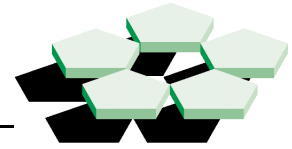
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Driver Vigilance Devices: Systems Review

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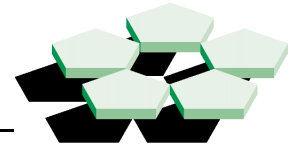
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Executive Summary

There has been considerable interest in alertness, vigilance and fatigue in safety critical occupational environments, particularly where exacerbating factors such as shift work are present. This study concerns a review of devices currently used within the railway industry, future proposed systems to measure driver vigilance or readiness to attend to signal aspects, and the appropriateness of the transfer of technology from other transport industries. The five key objectives of the study were to:

1. Conduct a comprehensive and systematic technology information search of driver readiness monitoring devices, and of methodologies and techniques that measure alertness and readiness.
2. Develop User Acceptance, UK Railway Context and Scientific feasibility criteria that a device would have to meet to ensure its suitability for use on the UK Rail Network
3. Evaluate candidate monitoring devices identified during the information search against the feasibility criteria, and recommend devices that would be suitable for piloting or further validation
4. Perform a high-level cost-benefit analysis of implementing a monitoring device, taking into consideration potential safety benefits and financial costs.
5. Identify a high-level device implementation plan and experimental design characteristics required for trialing and testing a device.

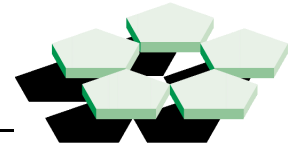
Out of thirteen devices identified in the information search, three were considered suitable for use by drivers and within the constraints of the UK Railway infrastructure. One device, EDVTCS, was considered mature in terms of design development and actual use, and would be the most suitable candidate to recommend for implementation on the railways.

Order of magnitude costs were calculated and assessed against estimates of safety benefits. The through life costs per cab would have to be less than £20 000 (per device per cab) for the device to be cost effective. It must be stated that a full and thorough cost-benefit analysis was not performed, and the costs and benefits identified are merely estimates.

The areas and levels of assurance required for device implementation were identified. These could be regarded as extensive, lengthy and possibly costly.

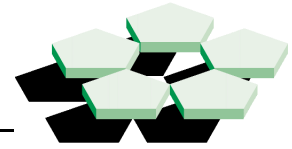
It was concluded that a monitoring device could possibly provide safety benefits, and that devices are available that reliably measure arousal. However, the prevalence of drowsiness related incidents would have to be fully investigated and quantified before a full cost-benefit assessment could be performed.

Recommendations include conducting research into driver's visual attention to determine possible precursors to incidences of driver distraction.



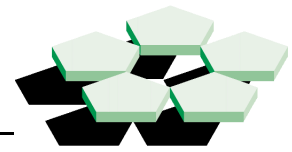
Abbreviations

ALARP	As low as reasonably practicable
ASLEF	Associated Society of Locomotive Engineers and Fireman
AWS	Automatic Warning System
CIRAS	Confidential Incident Reporting and Analysis System
CPU	Computer processing unit
DVD	Driver Vigilance Device
e.f.	Equivalent fatalities
EDA	Electrodermal Activity
EDR	Electrodermal Reaction
EDVTCS	Engine Driver Vigilance Telematic Control System
EEG	Electroencephalography
EKG	Electrocardiogram
EMC	Electro-magnetic current
EMG	Electromyogram
EOG	Electro-oculogram
ETS-PC	Eye tracking system PC
HAZOP	Hazard and Operability
HET	Hazardous Event Train Accidents
HMRI	Her Majesty's Railway Inspectorate
IT	Information Technology
MEG	Magnetoencephalography
OTMR	On Train Monitoring Recorder
P-way	Permanent way
PERCLOS	Percentage eye closure
SAS	Starting against signal
SPaD	Signal Passed at Danger
TOC	Train Operating Company
TPWS	Train Protection and Warning System
VAB	Vehicle Approval Board
Vpf	Value of prevented fatality



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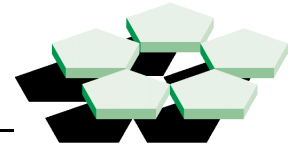
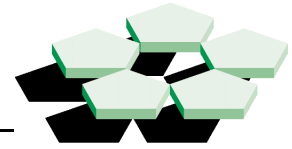


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1 Introduction

There has been considerable interest in alertness, vigilance and fatigue in safety critical occupational environments, particularly where exacerbating factors such as shift work are present. These environments include civil air operations, car, truck and train driving. In these settings, short periods of intense activity take place within long periods of monotonous work. These tasks often occur against a background of irregular work and rest schedules for the operator, which may also mean that sleep quality and duration are less than optimal.

Concern over maintaining the level of vigilance with which an operator addresses the task has given rise to a number of proposed devices for monitoring operator vigilance and alerting the operator to lapses of concentration on the task.

This study concerns a review of devices currently used within the railway industry, future proposed systems to measure driver vigilance and the appropriateness of the transfer of technology from other transport industries.

The objective of driver vigilance devices is to identify of the temporary loss of control of a train due to driver incapacitation, or identify the precursors to incapacitation. Traditionally vigilance devices (e.g. deadman's pedal, AWS) have measured frequency of actions taken by the driver, monitoring for loss of driver function rather than their level of arousal or attention to the driving task and their performance on the primary driving task. In addition drivers are reported to respond to these types of vigilance devices in an automatic manner as a result of becoming used to their temporal spacing (habituation), or anticipating their action (prediction) (Reference 1). Habituation and prediction can significantly reduce the effectiveness of traditional vigilance devices.

1.1 Purpose of research

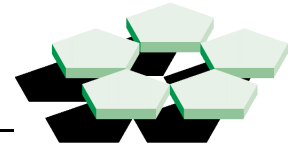
The purpose of this study is to provide Railway Safety with a practical understanding of the underlying physiological characteristics that could be used to monitor and evaluate driver vigilance. This understanding provides the foundation upon which the vigilance devices identified have been evaluated for reliability, validity and suitability for use in the UK rail environment.

The potential safety benefits of a vigilance monitoring device and the scientific concepts of vigilance and its measurement are presented in Section 2.

There have been five high-level project objectives:

1. The first is to conduct a comprehensive and systematic information search of vigilance devices, and of methodologies and techniques that measure vigilance (Section 3).
2. The second objective is to develop User Acceptance, UK Railway Context and Scientific feasibility criteria that a device would have to meet to ensure its suitability for use on the UK Rail Network (Section 4).
3. The third objective is to evaluate candidate vigilance monitoring devices identified during the information search against the feasibility criteria, and recommend devices that would be suitable for piloting or further validation (Section 5).
4. The fourth objective is to perform a high-level cost-benefit analysis of implementing a vigilance monitoring device, taking into consideration potential safety benefits and financial costs (Section 6).
5. The fifth objective is to identify a high-level device implementation plan and experimental design characteristics required for trialing and testing a device (Section 7).

The outcomes and recommendations from the study are presented in Section 8.



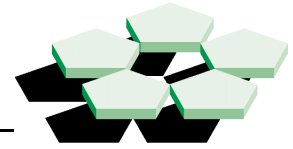
1.2 Scope of research

The study is restricted to a paper based evaluation of the “state of the art” as the first stage in what may become a longer term programme of work.

1.3 Key terms and concepts

The reader will encounter a variety of terms used in psychology and physiology for which there is no simple equivalent in common English usage. A glossary of terms used in this report is given below. The terms are employed consistently throughout the report. These definitions have mainly been derived from the Reference 2.

Alertness	The “optimum” state of arousal for executing tasks
Arousal	A general physiological state varying from coma and drowsiness to alertness and frantic excitement. Increased attention to and awareness of the environment rendering the organism better prepared for mental or physical action.
Attention	No clear definition exists
Automatic behaviour	Activities performed during a below 'conscious' state
Drowsiness	A phase of arousal between 'awake' and 'sleep', and may include micro sleeps
EEG (Electroencephalography)	The recording and analysis of changing electrical potentials due to the activity of the cerebral cortex (brain) measured from electrodes on the scalp.
EMG (Electromyography)	The recording and analysis of the electrical properties of the skeletal muscles.
Monitoring	Use of perceptual and cognitive resources to identify state changes in constantly available stimulus
Reliability	Proportion of tasks which are completed correctly and on time
Search	Use of perceptual and cognitive resources to identify random occurring events in perceptual space
Selective attention	A task environment in which the observer or operator must attend selectively to some stimuli or input channels while ignoring others that are active simultaneously.
Sleep	A condition of the body involving changes in a variety of biological functions, including temperature change, hormone secretion, and bladder operations.
Time-sharing	Allocation of perceptual or cognitive resources between two or more separate demands
Vigilance	A state of readiness to detect stimuli, appreciate context and respond accordingly. Typically achieved at the optimum level of arousal.
Vigilance decrement	A reduction in the state of vigilance (from optimal).
Workload	Is the portion of resources (i.e. maximum performance capacity) expended in the performance of a particular task. Because



human resources are limited it is important that the tasks performed do not overload human capacity and produce performance decrements. It is also possible to underload a person, where a small portion of resource is required to perform a task. In these work situations, a person is more likely to become bored, distracted or even drowsy.



2 Train Driving and Driver Readiness

The purpose of this section is to describe the factors that determine driver readiness, and how these factors could be measured. This is presented within the context of the driving task, driver reliability, and the causes of failures to detect and react to signals. In addition, the implications for safety are discussed with the use of SPaD incident data and SPaD case studies. As is explained during this section, driver readiness is the state at which a driver is ready to perceive, process and act on signal aspects and trackside signs. It is a function of the driver sustaining attention, their allocation of the driver's attention, and their level of arousal.

2.1 The train driving task

Porter (1992, Reference 3), produced a task analysis of train driving, describing the types of tasks that a driver is required to perform. These include:

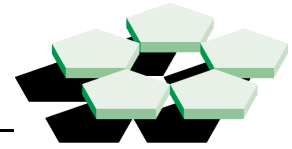
- Adhere to trackside signs, boards and indicators - requires vigilance to notice signs, recollection and application of route knowledge, decision making, and fast & appropriate reactions to information
- Monitor trackside and track ahead for trespassers and obstructions - requires vigilance, decision making and fast reactions
- Monitor men working on the track - requires vigilance, decision making and fast reactions
- Monitor and adjust speed of train - requires attention to speedometer, assimilation of information and decision making
- Adhere to signals - requires vigilance to ensure signal is not missed, recollection and application of route knowledge, assimilation of information and decision making, and fast reactions
- Respond to AWS system - requires vigilance to ensure signal is not missed, recollection and application of traction knowledge, assimilation of information and decision making, and fast reactions
- Respond to vigilance device - requires vigilance to ensure signal is not missed, recollection and application of route knowledge

The task of train operating, especially driving requires the application of a psychomotor (co-ordinated activation muscular systems), cognitive (information processing), sensory (use of visual, auditory and other senses) skills. These skills are learnt through training and reinforced and enhanced with experience. The specific skills required for train driving includes:

- The ability to remember and recall information,
- The ability to think ahead and evaluate the effect of several factors that may affect train performance,
- Fast reaction time
- Precision control skills
- The ability to maintain vigilance and concentration

The current signalling system relies on the driver to monitor for, and respond to danger and warning signals. Therefore, the ability to maintain vigilance and concentration, in addition to good vision, could be considered as key driver skills. Routes are currently being updated with signal protection systems that will prevent or minimise the consequences of SPaDs, thus improving passenger safety. However, even with these levels of train protection, (and current levels of driver selection and driver training), driver errors can occur. Halliday and Porter (1996, Reference 4) provides a categorisation and description of the errors that driver's could possible commit and the potential underlying causes. These include:

- Failing to spot a danger signal in time to initiate the appropriate braking



- Failure to apply route knowledge
- Failing to spot caution signals
- Failing to spot trackside signs, boards and indicators
- Failing to spot changes in track gradient or curvature (thus over or under speed)
- Responding to AWS system without knowing the type of signal aspect passed
- Spotting a danger signal but assuming that it will change (based on route knowledge)

Driving requires both vigilance skills and selective attention skills. The ability of a driver to execute these skills depends on their level of arousal. Decrements in vigilance, attention and arousal can contribute to driver error, possibly resulting in a SPaD incident. The concepts of vigilance, attention and arousal are discussed in the next section.

2.1.1 Vigilance

Definitions of vigilance differ between branches of science, mainly neuroscience and psychology. Neurologists equate vigilance with arousal, or alertness, or 'physiological efficiency' - (Henry Head 1926, Reference 5). They describe vigilance as the 'maximum state of physiological efficiency of the central nervous system'. This relates vigilance to the classification of sleep and wakefulness stages, or arousal levels. Levels of arousal range from coma, drowsiness, to alert.

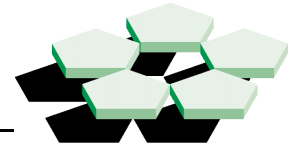
Psychologists tend to classify vigilance as a component of attention, along with monitoring and search, with vigilance being the ability to sustain attention, as opposed to select a focus for attention. A vigilance task is one that requires a subject to respond in some way to the occurrences of relatively infrequent and unpredictable (in time, space, or both) stimulus changes over relatively long periods of time. Boff and Lincoln (1988, Reference 2) describe vigilance tasks as requiring the detection of infrequent, simple signals over a prolonged period of time without rest, whereas a monitoring task involves more complex signals and/or more than one source for signals and/or continuous rather than discrete events. These distinctions are experimentally valid, but do not transfer readily to real world tasks, which are typically combinations of psychological task types.

Section 2.1.2 describes the relationship between arousal and attention (and therefore vigilance).

2.1.2 Attention and arousal

Wickens (1992, Reference 6) describes attention in terms of a limited resource metaphor. Attention can be allocated depending on the available mental resources (capacity) and the mental operations (loading) that must be carried out i.e. a supply and demand model. For example, resources could be used to perceive information from the body's sensory receptors (e.g. eyes and ears), in addition to deciding the required response (cognitive or mental processing) to information and executing a response (e.g. controlling hand movement). The concept of attention covers the following points:

- Attention involves the conscious processing of information
- Sources of information to be attended to can be external (e.g. data driven, such as trackside signals, or an auditory warning) or internal (e.g. from memory, such as route knowledge or timetable knowledge)
- It can be selective and directed to one or more of a number of signals/sources of information or positions in space (e.g. directed to a particular indicator light or alarm, or part of the trackside, depending on the perceived priority of the alarm or recalled location of a signal)
- It can be deployed with more or less intensity (e.g. time allocated to performing a task over another task, primary and secondary tasks, depending on the available mental resources and a person's mental capacity)



Arousal is a general state that affects a person's ability to carry out various functions of attention including maintaining vigilance, monitoring the environment and searching for objects. Levels of arousal range from coma, asleep, drowsiness, to alert. Henry Head (Reference 5), a neurologist, provides the definition of alert as 'maximum state of physiological efficiency' - this is more related to vigilance in the context of sleep and wakefulness (e.g. the classification of sleep/wake stages). Head's version of arousal deals with the state of the nervous system. In general terms, an increase in physiological arousal equates to an increase in the ability to make discriminative responses by perceptual and cognitive processes. This definition of arousal is captured in the Yerkes-Dodson Law, named after the researchers that first demonstrated the non-linear relationship between stress (or lack of stress) and performance (Yerkes and Dodson, Reference 7). One of the key principles of this law is Performance is generally related to arousal in the form of an inverted-U, with optimum performance generally at an intermediate level. Furthermore, the optimum value of arousal level is inversely related to the difficulty of the task.

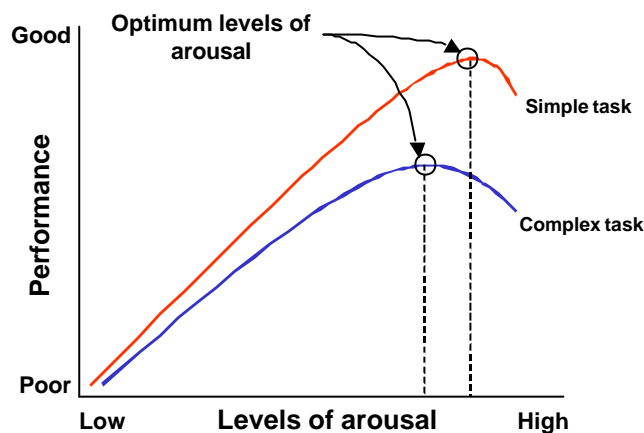


Figure 1: Performance as a function of arousal (The Yerkes-Dodson Law)

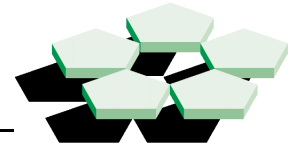
Easterbrook (1959, Reference 8) suggested that increases in arousal beyond the optimum level for performance has the effect of narrowing attention and thus neglecting some task relevant features. An optimum level of arousal has the effect of reducing attention on irrelevant information cues, expanding the attentional resources for information processing and thus optimising performance. Lower than optimal levels of arousal can lead to reduced task performance due to a decline in the ability to sustain attention, and increased probability of distraction. 'Performance' and 'arousal' in this context are only relative, but the relationship remains, depending on the task performed.

Low levels of arousal can be caused by environmental factors such as sleep loss and fatigue, time of day, or by task related factors such as driving duration, and perceptions of 'boredom', in addition to the consumption of certain drugs. High levels of arousal can be caused by anxiety (or 'worry'), either personal or task related. Placing a strain on a person's ability to allocate attention has similar effects on performance as high levels of arousal. The issue of low arousal levels, and attention allocation are considered more relevant to the nature of train driver task and will be discussed in the next two sections.

2.1.3 Low levels of arousal

The three contributors to low arousal that are relevant to this study are:

- Boredom
- Sleep loss
- Time of day



The state of boredom arises from performing repetitive or monotonous work, whilst still requiring to maintain attention. It is subjective and is perceived by people based on tasks being performed, and a person's motivation and ability to perform the task.

Sleep loss can be the prevention of any sleep for one or more nights, or the prevention of part of a night's sleep.

Level of arousal can be affected by the time of day at which a person is performing a task. During certain times of the day and night, performance and alertness are significantly impaired due to the human biological clock, which operates on a 24-hour cycle (circadian rhythm). The biological clock informs the body when to go to sleep and when to wake up. Levels of alertness are impaired between 12am and 6am. (Reference 9)

The effect of sleep loss, boredom and time of day has similar effects on task performance, and also manifests themselves in human behaviour in similar ways. People can suffer from diminished motor, cognitive and perceptual skills; for example reaction time to stimuli increases with low levels of arousal. Sleep loss, boredom and time of day effects can lead to feelings of drowsiness, and the beginning of the physiological signs of sleep. People can slip from alert to drowsy, to even the first stages of sleep. During these drowsy periods, it is possible to still attend and respond to simple reaction tasks. In a train driving scenario, drivers can potentially respond to the Driver Vigilance Device warning when in a drowsy state. Automatic behaviours, where a trance like state is entered, can be exhibited and awareness of tasks that are being performed is lost (Reference 9).

The drift from an alert state to a drowsy state can be manifested in body movements and behaviours. People begin to yawn, and adjust their posture more frequently, eye blink rate can increase, and the general muscle tone of the face changes.

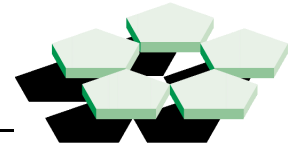
Boredom can also lead to distraction, even if a level of low arousal is not reached. Gibson (1999, Reference 10) in a review of Category A SPaDs (1994-1997) stated that 30% of drivers that reported the cause of their SPaD were attributed it to distraction. These distractions could be attributed to events outside of the cab, or events inside the cab. An example of this within the context of railway operations is a SPaD report dated November 2001, where a driver passed a signal at danger because they were preoccupied with an AWS fault (the driver was relatively inexperienced, having only been driving for 6 weeks).

A more tragic example of how the effects of possible distraction or inattention can have severe consequences is the Southhall Rail Disaster. The Public Inquiry (Reference 11) found that the HST involved in the collision was running with an isolated AWS system, and that the driver was inattentive for a period of time such that a double amber and then an amber signal were passed. The evidence presented at the inquiry was insufficient to conclude whether the lapse was due to drowsiness or fatigue, or to voluntary distraction/inattentiveness.

A vigilance monitoring device should identify when a driver's level of arousal is sufficiently low that they are not capable of responding to signals or trackside information. Furthermore, the ability of a device to identify when a driver is distracted from the task of monitoring for signals and trackside signs should also be considered.

2.1.4 Allocation of attention

Humans can fail when performing time sharing activities by prioritising tasks incorrectly, and shedding the critical information/task in preference to the non-critical. SPaDs caused by time-sharing with monitoring or interacting with in-cab equipment are not reported explicitly in SPaD reports (such as Gibson and Railway Safety's monthly SPaD report), but should be considered when assessing a vigilance monitoring device. A device should not add to the driver's workload, and should not be a distraction. Furthermore, a device could infer the driver's ability to respond to signals by detecting control actions initiated by the driver (e.g. use of traction brake controller).



2.2 Levels of driver readiness

Driver readiness has been defined as the state at which a driver is ready to perceive, process and act on signal aspects and trackside signs. It is a function of the driver sustaining attention, their allocation of the driver's attention, and their level of arousal. Current vigilance devices are only capable of determining whether a driver is incapacitated, asleep or dead. They are not able to detect subtle changes in behaviour or physiology that may indicate a reduced capacity to drive the train. The information presented regarding the causes of driver errors, SPaD data, and the discussions regarding vigilance, arousal and attention indicates that driver readiness can be broken down into the following levels:

1. Driver incapacitated/asleep/dead
2. Driver alive, but drowsy or not sufficiently alert
3. Driver is sufficiently alert, but is not attending to the train operating tasks
4. Driver is sufficiently alert, but is inappropriately time-sharing between train operating tasks
5. Driver is sufficiently alert and is attending to the appropriate train operating tasks

To ensure that driver's are sufficiently alert and sufficiently attentive to detect and process signal aspects and other critical information, potential devices should consider each of these levels of driver readiness. A driver's readiness state may move between Level 5 and 3 during a journey, and even Level 2 given the wrong environmental, task and personal factors.

2.2.1 Possible measures of driver readiness

Generally, driver readiness can potentially be measured by using task performance, monitoring driver behaviours and measuring physiological changes in a subject. The techniques used in research to measure vigilance, and effects of arousal level on task performance can be summarised as follows:

- Correct detection and omission errors - Correct detection is where the detection rate and the number of signals detected correctly are measured. Omission errors represent the number of stimulus that were not detected.
- Commission errors - This is where false alarms are measured - i.e. where a stimulus is reported when none is presented.
- Reaction time - This is where the time taken to respond to a stimulus is measured. Reaction time is related to levels of arousal.
- Physiological changes - These measure the body's response to a state of reduced vigilance or arousal. There are several techniques that are related to reduced task performance, including measuring brain activity, skin electrical activity, eye and facial feature changes, heart activity and so on. These are generally measured in real time. Physiological measures are usually considered to be related to arousal.

Task error measures would not be appropriate for a real-time measure of driver readiness, even though they are a true measure of readiness. These are best suited to controlled laboratory environments. Reaction time and physiological changes would be suited to real-time monitoring. Eye-movements, fixations or head movements and posture could be used to monitor visual attention. Merat et al. (2002, Reference 12) identified that fixation time on signals is different for different signal aspects. It may be possible to monitor fixation times to determine the correct allocation of attention.

Section 3 describes the results of the information search on vigilance monitoring devices.



3 Technology Information Search

The first objective of the study was to conduct a comprehensive and systematic information search of devices, and of methodologies and techniques that measure driver readiness.

A search was conducted across all industry sectors to include rail, air, land, and sea, civil and defence industries. The search has consisted of:

- Internet keyword search
- Contacting relevant research institution, organisations and government departments
- Literature search including journal abstracts, public library databases, and university library databases
- Marketplace review, which may include product literature reviews, visits and attending demonstrations

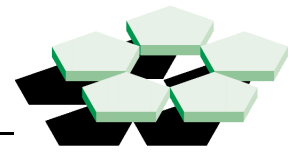
The findings of the search have been recorded in two databases, one containing information on vigilance devices, and one containing information regarding physiological indices. Examples of database entries presented in Figure 2.

3.1 Device database

The vigilance device database contains information regarding devices that are either currently available to procure, in prototype or testing phase, or in design or concept phase.

Database sections and fields were designed according to the study's categories for feasibility - User acceptance, UK Railway Context, Scientific, and cost-benefit acceptance. The key headings and sections of the database are:

- Contact details - containing current contact details of the company/organisation that currently owns the intellectual property rights to the device, and any patent details received
- Description and use of equipment - provides an overview of the physiology index measured, the methods of measurement, invasiveness and intervention/alerting methods
- Set-up and calibration - describes the practical issues of setting up the device
- Technical description - contains details of the device's power requirements, reliability, and training requirements
- Technological maturity - this provides the current development status of the device and where it is currently being used



3.1.1 Overview of device database contents

Table 1 provides an overview of the status and content of the device database

Device	Device Company	Country	Measure of readiness
Engine Driver Vigilance Telemetric Control System (EDVTCS), 3rd Generation	J-S Co. NEUROCOM	Russia (contact details are for Luxembourg)	EDA and EDR
MicroNod Detection System (MINDStm)	Advanced Safety Concepts, Inc (ASCI)	USA	Head movements
Eye Tracking Alertness monitor	Future of Technology and Health	USA	Eyelid droop, pupil occlusion, eyelid closure
ABM Drowsiness Monitoring Device (DMD)	Advanced Brain Monitoring Inc	USA	EEG
Photo Driven Alert System	Michael Myronko	UK	Blink Rate
Device for monitoring haul truck operator alertness	Australian Coal Association Research Programme (ACARP)	Australia	Reaction time
ETS-PC Eye tracking system	Applied Science Laboratories	USA (UK contact details)	Eye closure
faceLAB™ 2.0	Seeing Machines	Australia	Eye blinks, eye closure
Vehicle Driver's Anti-Dozing Aid (VDADA)	BRTRC Technology Research Corporation	USA	Head movements and eye closure
Copilot PERCLOS Monitor	Driving Research Center	USA	PERCLOS
Alertness Monitor ambulatory eye blink monitor	MTI Research Corp.	USA	Eye blink
Eye tracker and steering wheel sensor	Bristol University	UK	Uses ASL's eye tracking technology
Hypovigilance Diagnosis Module (HDM) and Driver Warning System	Part of the EU's Information Society Technologies (IST) research programme	Greece	Not available

Table 1: Overview of device database contents

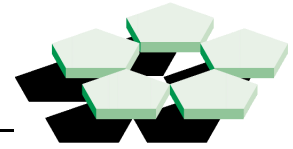
The product of the information search is given in Appendix A.

3.2 Physiological measures database

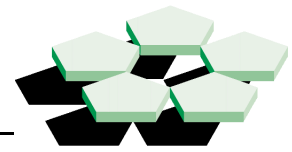
The information search has identified a range of physiological indices that are claimed to measure alertness, fatigue or vigilance. The database captures information regarding the method by which the physiological index measures the physiological variable, how the index is correlated to performance, what the thresholds to impaired performance are, and the issues associated with the index.

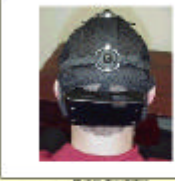

The database provided a method of collecting data from research papers to support the scientific viability of the device that utilises the measure. The product of physiological measures information search is given in Appendix B.

Eight measures have been described in detail. These are:



-
- Electroencephalograph (EEG)
 - Eye blink activity (blink duration, blink amplitude and blink rate)
 - Eye movements
 - PERCLOS (Partial eye-closure measure)
 - Electrodermal Activity (EDA)
 - Heart measures
 - Reaction time to a stimulus
 - Head movements



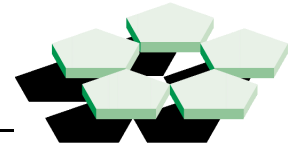
DRIVER VIGILANCE DEVICE/TECHNOLOGY DATABASE	
Name of device: Alert Drowsiness Monitoring Device (DMD)	
Company issuing IPR:	Advanced Brain Monitoring Inc
Contact details:	
Contact company or organisation:	Advanced Brain Monitoring Inc
Contact person:	Ms Chris Bala
Phone number:	700 720 0094
Postal address:	8800 Rio Pico Drive, Suite A
City or town:	Carlsbad
State or State:	California
Post/Zip Code:	92008
Country:	USA
Source of information: Google internet search	
Description and use of equipment:	
Type of address:	Device name/label/name
Product or category:	EEG
Values available:	Not clear from web site
Function:	The electrodes dispense a small amount of conductive gel.
Method of measurement:	Electrodes for measuring EEG are housed in a baseball cap-type headset. The cap is worn on the head during a shift. EEG data is transmitted by radio signals to a analyser which is located in close proximity to the user. Feedback on the data is provided in real time. The device monitors for shifts in alertness, using the company's patented B-Mem software. The EEG data is quantified by classifying each second on a continuum from highly alert to onset of sleep.
Other equipment in related address:	The device presents and auditory warning to the driver in the event of a drowsiness state being detected.
Set up and calibration:	
Installation and use of equipment:	One-time 15-minute calibration required for a new user. Cap application is 3-5 minutes.
Use of time:	See above
Method of calibration:	Calibration only required for initial use.
Frequency of calibration:	Calibration only required for initial use.
Technical description of equipment:	
Material:	Actual drowsiness
Manufacturer:	Not clear from web site. Does it need cleaning? How often do you need to replace?
Equipment used:	Caps come in four different sizes, according to head size. A processor/analyser is required to compute the EEG data.
Equipment required for operation:	Not clear from web site
Training required:	Not clear from web site
 	
Technology maturity:	
Availability:	Available now to buy
How the device has been used:	Not clear from web site
How the device has been used in field:	Not clear from web site
Which standards have been used for:	
Database admin:	
Unique database number:	117022002
Record created by:	Adam Whitlock
Record updated by:	
Other information required:	Yes <input type="checkbox"/> No <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/>
Has permission been given to publish information?	Yes <input type="checkbox"/> No <input type="checkbox"/> Not sure <input type="checkbox"/>

Database of physiological indices	
Name of index:	Electrodermal activity (EDR)
Physiological variable measured:	Alertness Vigilance
Description of index:	EDR is the electrical activity, resistance and potential, at the skin surface. The level of activity reflects certain mental states. It has been shown that electrical resistance of the skin is not a constant value, and is liable to two types of changes: 1. Slow variations of electrodermal resistance, which change over a period of minutes and hours. These relate to the nervous stimulation to muscles. 2. Fast changes of several hundred Ohm or kOhm as a response to sensory or emotional stimulation. This is a derivative of the electrodermal resistance.
How does the index measure the variable?	EDR is measured using electrodes attached to the skin. These measure the electrical activity at the skin's surface over time. The measures are generally amplified by a preamp and then recorded on a polygraph.
How is the index correlated to performance?	A relationship between electrodermal activity and arousal has been established in Reference 1 and 2. Reference 2 showed that the electrodermal activity (skin potential) reduced in negativity according to a decrease in task performance. Reference 3 showed that the frequency of electrodermal responses decreased preceding a task error. Furthermore, the decrease in EDR was correlated with reaction times during a visual recognition test.
How are measurements taken?	Which body parts are the measurements taken? How is it done? How often are measurements taken?
What are the measure's indicators for vigilance?	EDR is useful as measure of the level of arousal when subjects feel drowsy but not on the brink of falling asleep. Reference 2 and 3 show that EDR is a reliable measure of task error before EEG measures show the presence of sleep indicators (e.g. rhythmic alpha activity and theta activity).
Problems with this index:	Electrodermal responses to emotional and sensory stimulation are affected by muscle electrical activity and spontaneous electrical responses. These artifacts have to be removed to discriminate arousal related responses.
References for information:	1. Mental activity and electrodermal phenomena, in J.L. Andrade (ed.), Psychophysiology: Human Behaviour and Physiological Response, 3rd edn (Hilldale p175-180). 2. Nishimura, C., and Nagumo, Jin-ichi, 'Feedback control of the level of arousal using skin potential level as an index' 1995, Ergonomics, 29, 5, 605-612. 3. Doroshkin, Y.B., Dement'enko, M.V., Korotkova, L.G., Makov, A.P., Shakhnarovich, V.M., Zakharov, P.V., 1988, International Journal of Psychophysiology, 30, 1-2, 1207.
Record created on Unique record number:	210462002 10
Record created by:	Adam Whitlock

Devices technology database example extract

Physiological measures database example extract

Figure 2: Example extracts from the device and physiological databases

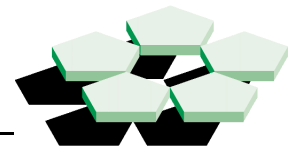


3.3 Conclusions of information search

In total 13 devices were identified. Of these, one was based on technology developed by another device company (Eye tracker and steering wheel sensor), one had been taken off the market by its manufacturers (Alertness Monitor ambulatory eye blink monitor), and one did not provide any data on their product. Ten devices were identified for the process of feasibility assessment. Eight of the thirteen devices employed some form of eye movement or blink behaviour measure. Heart measures, were not represented by the device technologies. These measures may have been identified by device manufacturers as being inappropriate for practical applications, or may not have had sufficient investment in their development as applied tools for real time monitoring.

Measures or monitors of visual attention have not been identified during the information search. The technology may be available to track and analyse eye movement reliably, but the knowledge about eye behaviours such as search patterns and eye fixations may not be available. The increasing sophistication of eye tracking technologies could lead to a greater understanding of eye movements in the context of train driving tasks which, in the future, may lead to the production of an attention monitoring device.

The criteria against which devices should be evaluated are presented in Section 4.



4 Feasibility Criteria

The feasibility criteria developed for the study were:

- User Acceptability criteria
- UK Railway Context criteria
- Scientific criteria for physiological indices

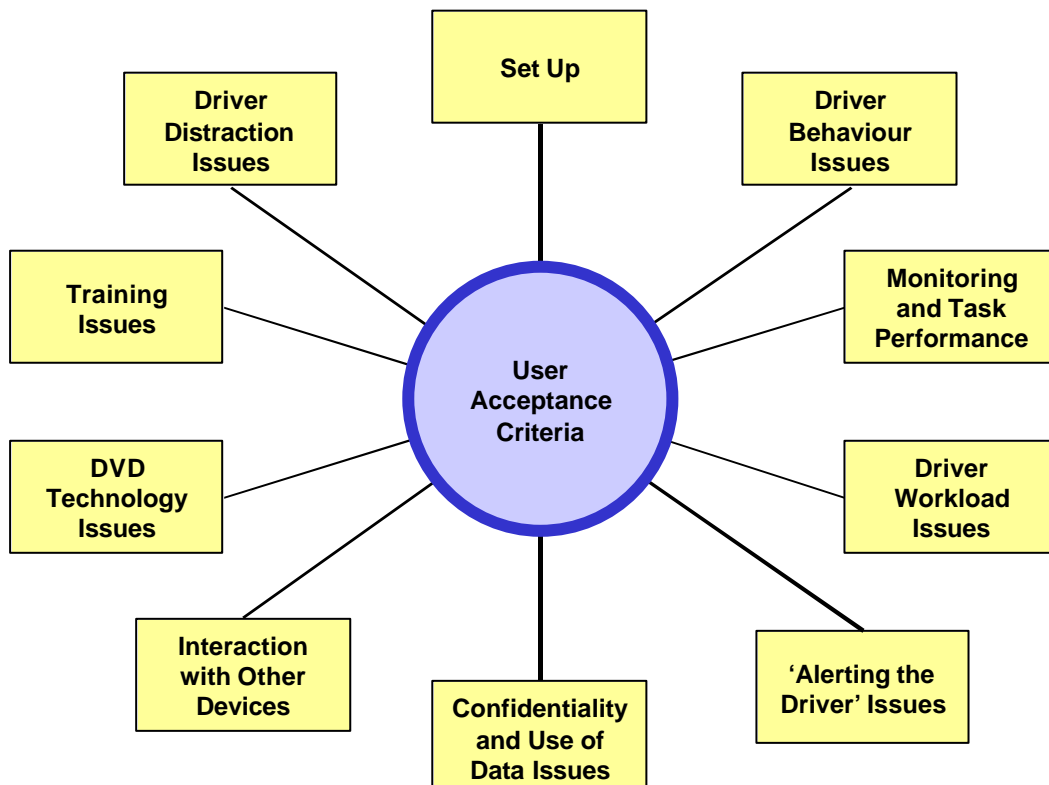
The User Acceptability criteria and UK Railway Context criteria were developed during a working group convened by Railway Safety (Reference 13). The attendees at the meeting included representatives from ASLEF, TOC's, Railway Safety and the HMRI. The criteria (presented in the tables below) relate to the characteristics, specifications and properties of the device. Additional practical criteria relating to the implementation of a device were also generated during the meeting, but these are not documented in these tables. A list of implementation issues is presented in each section.

The scientific criteria were developed from basic principles of research design and analysis.

Each criterion has been designated with a unique identification number, so that changes to the criteria can be tracked. If a criterion was changed, then it was reallocated with a number and cross-referenced to its antecedent.

4.1 User Acceptability Criteria

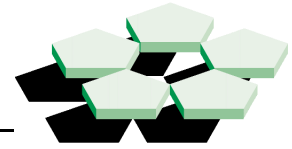
The key areas for User Acceptability were as follows:



The User Acceptability Criteria and tests presented in **Error! Reference source not found.** were consolidated from the issues discussed and recorded during the Working Group meeting.



No.	Criteria	Test
UA1.	The device must not distract the driver from their primary task or responding to other safety devices (e.g. AWS, TPWS)	<p>The device must not present false alarms</p> <p>A device that requires the driver to perform a secondary task would be classed as a distraction</p> <p>A device with a time base frequency of operation would be classed as a distraction</p>
UA2.	The device must not be invasive	<p>The device should not take measurements from:</p> <ul style="list-style-type: none"> • Penetrating the skin • Body cavities • Skin contact with adhesive gel <p>Skin contact is acceptable.</p>
UA3.	Wearable devices must accommodate the variations in driver anthropometric dimensions	<p>The anthropometric range is defined by the part of the body that the device has to be worn.</p> <p>The device will require sufficient adjustability to accommodate the defined anthropometric ranges.</p>
UA4.	Devices that take measurements remotely must accommodate variations in sitting height	<p>Devices such as head trackers and eyetrackers that take measurements remotely must be able to work for the smallest and largest drivers (in terms of sitting height).</p>
UA5.	Devices must accommodate variations in driving posture and driver behaviours whilst driving	<p>Driver behaviours include:</p> <ul style="list-style-type: none"> • Adjusting posture to view outside the cab • Adjusting posture to promote blood flow and aid comfort • Adjusting posture to reverse the train • Adjusting posture to perform precision driving tasks such as coupling or lining up with station markers
UA6.	The device shall accommodate physiology and behavioural changes in the driver that result from the state of the cab's thermal and illumination environment	<p>Measurements taken from the device shall not be affected by:</p> <ul style="list-style-type: none"> • Sweating • Body and skin temperature fluctuations • Responses to bright sunlight
UA7.	Devices must accommodate religious head-dresses worn by Sikhs, and the wearing of hard-hats	<p>Devices that take measurements directly from the scalp will not be acceptable.</p>
UA8.	Devices must accommodate corrective spectacles and sunglasses	<p>Devices that are not able to take measurements when corrective spectacles and/or sunglasses are worn will not be acceptable.</p>
UA9.	Calibration of the device should only be required once during a driver's shift	<p>If a device requires calibration, this should be valid until a change of driver occurs.</p>
UA10.	Calibration to the driver's physiological state should not take longer than 5 minutes	<p>A calibration time of over 5 minutes would be unacceptable.</p>
UA11.	If the device requires up-to-date data on the driver's physiology, then it should be done every 5 years	<p>Drivers have medical examinations every 5 years, so the device should accommodate this practice.</p>
UA12.	The device should present an auditory alert to the driver in the cab	<p>A device that did not have an alert would be unacceptable.</p>
UA13.	The alert should be distinct from other in-	<p>The frequency of the alert tone would be compared to the</p>



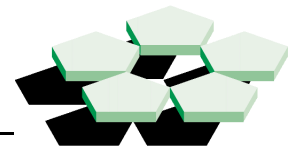
No.	Criteria	Test
	cab safety alerts	frequency of current in-cab alert tones. Requirements for alert tones in train cabs is given in the Railway Group Standard GM/RT2161
UA14.	The alert should not be masked by other alerts, horns or ambient cab noise	The intensity (loudness of the alert) of the alert would be compared to the typical noise intensities experienced in cabs. Noise intensity levels in cabs is given in Railway Group Standard GM/RT 2160.
UA15.	The device shall have a control to cancel / acknowledge an alert	A device that did not have a manual alert acknowledgement / cancellation control would be unacceptable.

Table 2: User Acceptance Criteria

A display showing levels of vigilance/alertness may also be useful, to enable drivers to periodically monitor their own physiological state, however this is not a mandatory requirement.

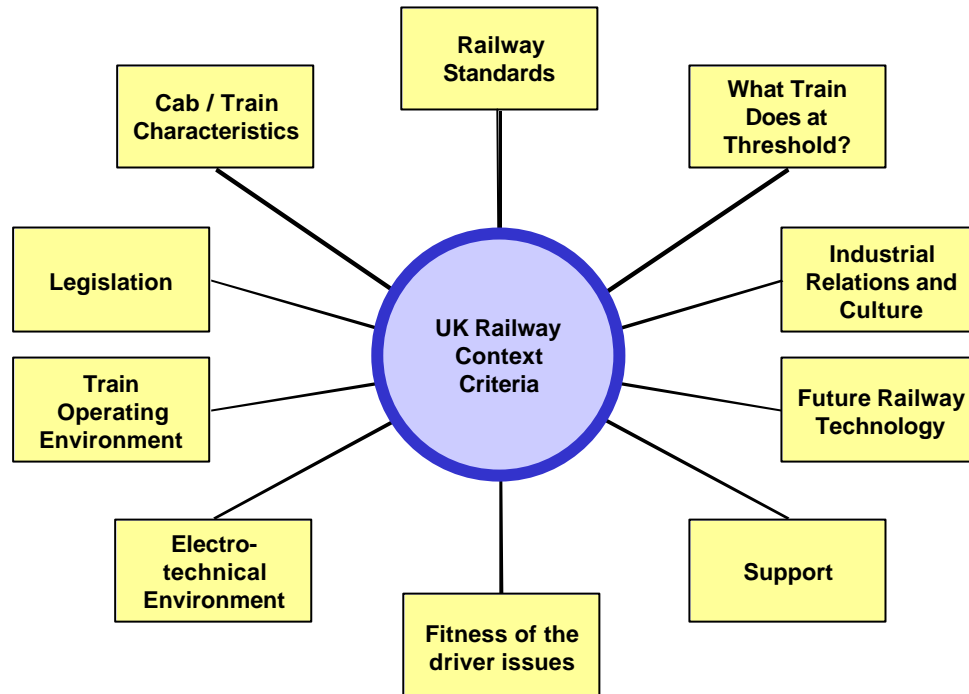
Issues relating to the implementation of the device were identified during the workshops. These issues are not considered as requirements against which devices have to be measured, but they are considered important to the successful implementation of a device. The user implementation issues include:

- The ergonomics implications of device control and display location
- The set-up of the device using the driver's key
- The situation when a train is already set up for a driver when they start their shift, and the implications for calibrating the device
- How the device may be interfaced with other safety devices and other human interface components (e.g. traction brake controller, horn etc.) to minimise driver workload
- How the device responds to repeated alarms
- Confidentiality if a driver is relieved on route
- Using the device as a driver support tool, as opposed to a blame tool
- Change management and 'buy-in' from stakeholders (especially drivers)
- An analysis of the training needs to use and respond to the device would be required



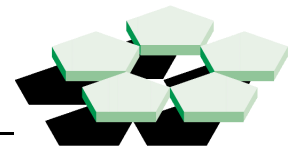
4.2 UK Railway Context Criteria

The key areas for UK Railway Context were as follows:



The UK Railway Context Criteria and tests presented in Table 3 were consolidated from the issues discussed and recorded during the Working Group meeting. These criteria relate to the appropriateness of each identified vigilance device for the UK rail industry.

No.	Criteria	Test
RC1.	The device shall have the facility of being connected to other train interface components (such as the traction brake controller and the AWS)	Once implemented, driver's may want the device to take consideration of their control actions, other safety alarms, or complex driving tasks and scenarios. Also, it should be possible to connect the device to the emergency brake.
RC2.	The device should have the facility to record and store physiological data	A device that did not record and store data would be unacceptable.
RC3.	The data recorded and stored on the device should be easy to retrieve and understand	If training was required to retrieve and interpret the stored data, it would be undesirable.
RC4.	The device shall have the facility to connect with the train's OTMR	This will relate the physiological data to the train control data.
RC5.	Eye tracking devices will have to be compatible with behaviours adopted by drivers in trains with in-cab signalling.	Eye-tracking devices should be able to accommodate 'head-down' activities as well as 'head-up' activities.
RC6.	If the device uses telemetry for transferring data, data transfer should not adversely affect current and future train-to-track wireless communications	The frequency and power at which the data is transferred will be assessed against current and future train-to-track wireless communication properties.
RC7.	If the device uses telemetry for transferring data, data transfer should not be adversely	The frequency and power at which the data is transferred will be assessed against current and future train-to-track



No.	Criteria	Test
	affected by current and future train-to-track wireless communications	wireless communication properties.
RC8.	The device should be robust against magnetic (or otherwise) interference from traction motors, overhead power cables and the electrified third rail	The EMC protection provisions of the device will be assessed against current and future magnetic (and otherwise) interference in the train cab.
RC9.	The device shall be compliant with GM/RT/2000 - Engineering Acceptance of Rail Vehicles	The device will be evaluated in the light of GM/RT/2000
RC10.	The device shall be able to operate in both air-conditioned and non-air conditioned environments	The operating temperatures and humidities will be evaluated against the range of environmental conditions in a cab, both during working hours and non-working hours (e.g. at night in the yard, sidings or depot).
RC11.	The device shall not add to the thermal load of the cab	The heat outputs of the device will be evaluated.
RC12.	The device shall be able to operate in both day time and night time illumination conditions	The operation of the device shall not be affected by dark or bright conditions.
RC13.	The device manufacturer shall be able to provide an operating manual	It would be unacceptable if a manual could not be provided.

Table 3: UK Railway Context Criteria

Issues relating to the implementation of the device were identified during the workshops. These issues are not considered as requirements against which devices have to be measured, but they are considered important to the successful implementation of a device. The railway context implementation issues include:

- Procedures relating to taking trains out of service for defective equipment
- Fitness for duty and the implications of a driver being continually alerted by the device
- The implications of interfacing between the device and other safety devices such as the DSD, emergency brake and other controls, including climate controls
- The implications for the current DSD
- The requirement for intervention by the train (e.g. application of brakes) in the event of a warning, and the level of an intervention
- General health and safety issues with respect to wireless data transfer and effects of radiation
- The requirement of fitting a new device in accordance with rolling stock service intervals
- The following of Railway Approval Regulations
- Device control and display location and the implications of fitting the device to the wide range of rolling stock, finding space, and gaining approval for the installation
- The requirement for bench testing, installation testing and trials
- Approval under technology standardisation
- The requirement for the device to accommodate the current practices for booking on to a shift, including drivers deeming themselves fit and remote booking on
- The ownership of and responsibility for the devices including installation, maintenance, training and disposal
- 'Future-proofing' of equipment in terms of I.T.

The process of device implementation is discussed and presented in Section 7.1.



4.3 Scientific Criteria

An appropriate set of scientific criteria is vital to ensure that the candidate device is fit for purpose. The device must be demonstrated to detect, measure and record what it claims to, and do so reliably and consistently for all users. The device must also be specific enough not to present false alarms, which would reduce the confidence the driver has in the device. In addition, the device should be sensitive enough to detect a significant number of error-producing physiological conditions (e.g. loss of attention or fatigue). The following list provides the key scientific areas that the criteria must address:

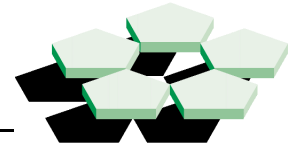
- General - related to the publishing of research information on the physiological measure and the impartiality of any research conducted on the measure
- Internal validity - related to the experimental design, use of subjects and statistics, including:
 - Criterion validity - related to the results of the experiment
 - Reliability - related to the consistency of the experiment
 - Sensitivity - related to the ability of the measure to consistently detect a potential error-producing physiological state, across the target audience
 - Specificity - related to false alarms
- Generalisability/External validity, including:
 - Population validity - related to subject variability, and application of results to the wider population
 - Ecological validity - related to how representative the research was of train driving tasks

There may also be a need to investigate the effectiveness of on-board vigilance alarms provided by devices.

For the purposes of this study, the scientific feasibility will be assessed using literature obtained during the information search. It is recommended that this literature-based assessment is substantiated with a formal experiment. Section 7 describes the high-level experimental design requirements for testing the scientific feasibility of a candidate device.

Table 4 presents the scientific criteria against which a device should be assessed.

No.	Criteria	Test
	Internal validity	
	General	
SC1.	What are the measures of task performance used to validate the device? Does the task and performance measure relate to the driving task?	The task used in the experiment and the performance measures should be compared to descriptions of train driving tasks, and driving skill requirements. The range of task fidelity could be: <ul style="list-style-type: none"> • Actual train driving • Train driving simulation in a simulator • Train driving simulation on a desktop • Lab based tasks
SC2.	Does the device measure what it's supposed to operationally? What else could the test be measuring?	The definition of what is purported to be measured should be compared to what is presented in research papers (e.g. method of collecting data) and how measurement artefacts are countered. For instance, a device that uses heart rate should follow recognised methods for measuring the number of beats per second.



No.	Criteria	Test
SC3.	Does the device measure what it's manufacturers claim, conceptually?	The documentation must define the item being measured, and provide a clear and valid correlation between the conceptual measure and the actual measure. For example, a device that claims to measure alertness should provide comprehensive evidence of the relationship between the measured variable (e.g. EEG) and the claimed variable (alertness).
SC4.	Does the physiological index that the device is measuring relate to the driver's performance?	Data must be provided on how the measure is correlated to a reduction in task performance.
SC5.	How do the device measurement results relate to subjective measures?	The device should be assessed using subjective measures and perceptions of task performance.
SC6.	Use of parametric tests (high power).	Data should be provided on the experimental design (use of statistics and sample size)
	Criterion validity	
SC7.	Has the index been benchmarked against other, established indexes that measure the same variables?	It may be appropriate to benchmark the device against EEG measures. EEG is well established at detecting sleep episodes, stages of sleep and severe drowsiness. In addition, the measure may also be assessed against behavioural antecedents of impaired performance, such as eye closure, periods of distraction etc.
SC8.	Are the test predictions correct? E.g. are the results significant?	Data should be provided on any statistics performed on the device during a test.
	Reliability	
SC9.	Is the device consistent in its measurement over a number of treatments?	Data regarding the number of treatments used during a device test should be obtained.
SC10.	Have repeated measures been used?	It would be advantageous if more than one test was carried out to prove the device.
	Sensitivity	
SC11.	How many times will the device miss an event? (False-negative)	Data regarding the percentage of missed events should be provided.
	Specificity	
SC12.	How many times will the device present a false alarm? (False-positive)	Data regarding the percentage of false alarms should be presented.

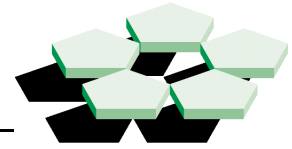
Table 4: Scientific criteria



No.	Criteria	Test
	Generalisability/ external validity	
	Population validity	
SC13.	Does it measure the same events for all people?	Describe sample size, group and type
SC14.	How did the results perform between subjects?	Specify whether all subjects gave positive results, and give justifications for differences
SC15.	How did the results perform across subjects?	Specify whether subjects gave the same results (variability of results across subjects)
SC16.	Does it take into consideration subject variability?	Check for any subject screening (sleep disorders, drugs etc.)
SC17.	Does the population used for the test match train driver population characteristics?	Compare age, sex etc. distributions for sample and for train drivers.
	Ecological validity	
SC19.	Does it generalise to train driving situations? I.e. do the test conditions and tasks match driving conditions and tasks?	Describe experimental environment and tasks performed
SC20.	What was the duration of the test?	Give duration of test and compare to driving times

Table 4: Scientific criteria (cont)

The evaluation of the devices identified in the technology information search is presented in Section 5.



5 Device Evaluation

The objective of the evaluation is to identify those devices that could be considered for further testing, trialing and analysis. A requirement of the project is to identify products that are suitably mature for use on the railway, with minimum design modifications. Each device was evaluated against the feasibility criteria described in Section 4:

- User Acceptability criteria (Table 2)
- UK Railway Context criteria (Table 3)
- Scientific criteria for physiological indices (Table 4)

5.1 Process for device evaluation

The logic structure for evaluating the device against the feasibility criteria is given in Figure 3:

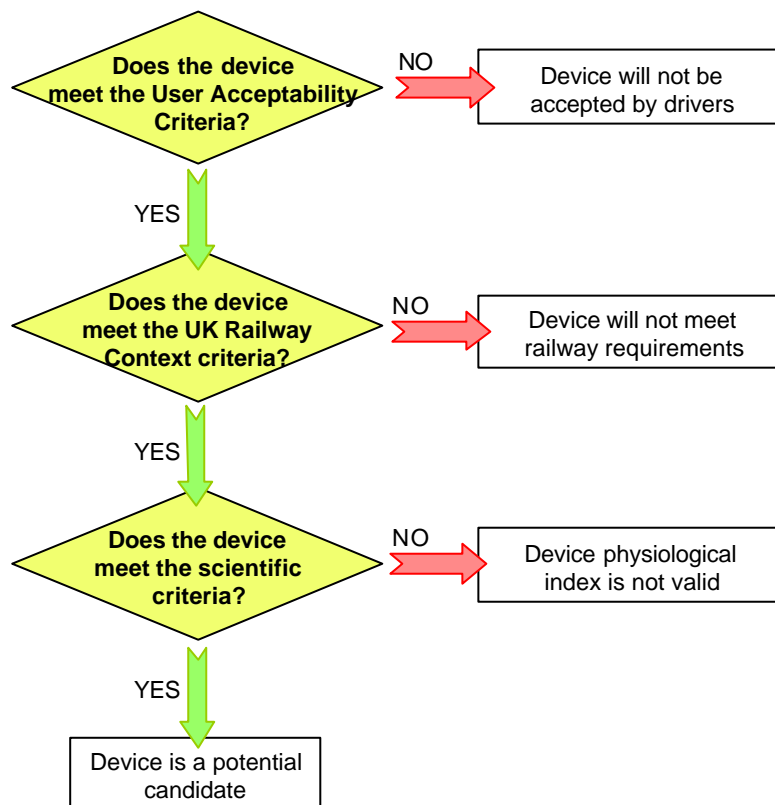
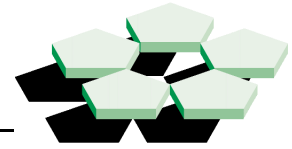


Figure 3: Logic structure for device evaluation

User Acceptance is the most important aspect of device feasibility. The importance of User Acceptance was emphasised by the attendees of the first workshop (Reference 13). If a device is not acceptable to drivers then it will probably be subject to resistance and mis-use.

The device data gathered during the information search was evaluated against each feasibility criteria for simple yes/no compliance. An example of how the results of the device evaluation were captured is given in Table 5:



Device:	e.g. Eye-blink monitoring camera		
No.	Criteria	Criteria Met (Y/N)	Reason for criteria not being met
UA3	The device must work with BS 1865 approved sunglasses	N	Camera is unable to penetrate glasses

Table 5: Example of device evaluation

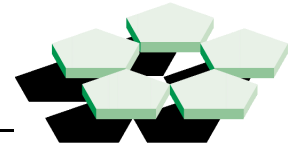
A device was considered unsuitable if it failed to meet any of the User Acceptance and Railway Context Criteria. Due to the nature of the scientific feasibility assessment, only comments on the relative merits (in terms of theory development) of the device's physiological measure, and the extensiveness and quality of the underlying research are provided.

The reasons for non-compliance are documented. Non-compliance issues could be presented to the device companies, so that they could suggest methods of redesigning their products to ensure compliance.

The analysis conducted for each of the criteria categories are given in Appendices C, D and E. A summary of the results are presented in Sections 5.2 (User Acceptance), 5.3 (Railway Context Acceptance), and 5.4 (Scientific Criteria).

5.2 Results of User Acceptance evaluation

The analysis of the User Acceptance evaluation is reported in Appendix C. The results are summarised in Table 6:

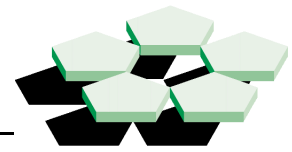


	Device	Device Company	Reason for non-compliance
May be suitable	Engine Driver Vigilance Telemetric Control System (EDVTCS), 3rd Generation	J-S Co. NEUROCOM	
	MicroNod Detection System (MINDStm)	Advanced Safety Concepts, Inc (ASCI)	
Unsuitable	Eye Tracking Alertness monitor	Future of Technology and Health	<ul style="list-style-type: none"> Device does not accommodate sun glasses
	ABM Drowsiness Monitoring Device (DMD)	Advanced Brain Monitoring Inc	<ul style="list-style-type: none"> Device is invasive as it uses conductive gel to improve the contact between the user and the sensors Device has to be worn on the head of the driver, therefore not compatible with head wear or hard hats
	Photo Driven Alert System	Michael Myronko	<ul style="list-style-type: none"> Device worn on ear so is difficult to wear spectacles comfortably
	Device for monitoring haul truck operator alertness	Australian Coal Association Research Programme (ACARP)	<ul style="list-style-type: none"> Device requires a secondary task
	ETS-PC Eye tracking system	Applied Science Laboratories	<ul style="list-style-type: none"> Device currently does not provide an alert
	faceLAB™ 2.0	Seeing Machines	<ul style="list-style-type: none"> Device currently does not provide an alert
	Vehicle Driver's Anti-Dozing Aid (VDADA)	BRTRC Technology Research Corporation	<ul style="list-style-type: none"> Device has to be worn on the head of the driver, therefore not compatible with head wear or hard hats
	Copilot PERCLOS Monitor	Driving Research Center	<ul style="list-style-type: none"> Device only works at night

Table 6: Summary of device evaluation outcomes

The evaluation shows that only two devices are acceptable against the User Criteria. The Engine Driver Vigilance Telemetric Control System (EDVTCS), 3rd Generation device passes all of the applicable criteria. UA1 (device distraction) has been met pending a trial of the device. The device's auditory characteristics would have to be assessed for compliance against Railtrack's noise intensity standard GM/RT2160. The effectiveness of the MicroNod Detection System (MINDStm) would have to be evaluated with respect to the donning of head dresses and hard hats, and to the height of cab ceilings. Both these devices qualify for assessment against the UK Railway Context criteria (Section 5.3).

The ETS-PC Eye tracking system may also be a future suitable candidate however, it currently does not incorporate an alert.



5.3 Results of UK Railway Context evaluation

The MicroNod Detection System (MINDStm) and Engine Driver Vigilance Telemetric Control System (EDVTCS), 3rd Generation devices qualified for an evaluation against the UK Railway Context criteria.

The analysis of the UK Railway Context evaluation is reported in Appendix D.

The evaluation found that both devices may be acceptable, however further information is still required to fully test the devices against some of the criteria. The key issue for both devices is to determine whether the devices would be compatible with the EMC environment within a train cab. This is especially the case for the MicroNod Detection System. The electromagnetic environment in train cabs may compromise the effectiveness of the system, as it measures changes in electric charge on the device's surface due to user head movements.

The Engine Driver Vigilance Telemetric Control System (EDVTCS), 3rd Generation has the greater potential as it is already being used on a rail network. It may be easier to integrate with current rail safety devices, such as the Driver Safety Device. The device qualifies for assessment against the scientific criteria.

5.4 Results of Scientific Criteria evaluation

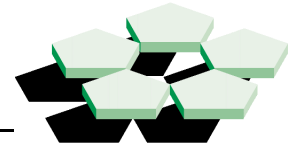
For the purposes of this study, the scientific feasibility was assessed using literature obtained during the information search. The EDVTCS device manufacturer representative provided research documentation for the assessment. The references for these are:

1.	Estimation of the time delay between performance error and its subjective perception during drowsiness	Dorokhov, V.B., Dementienko, V.V., Koreneva, L.G., Markov, A.G., Shakhnarovitch, V.M., Zakharov, P.V., 1998, International Journal of Psychophysiology, 30, 1-2, p95.
2.	Hypothesis about the nature of electrodermal reactions	Dementienko, V.V., Dorokhov, V.B., Markov, A.G., Koreneva, L.G., Shakhnarovitch, V.M., Tarasov A.V., 1998, International Journal of Psychophysiology, 30, 1-2, p267.
3.	On the possibility of using EDR for estimation of vigilance changes	Dementienko, V.V., Dorokhov, V.B., Markov, A.G., Koreneva, L.G., Shakhnarovitch, V.M., Zakharov, P.V., 1998, International Journal of Psychophysiology, 30, 1-2, p267.
4.	The peculiarities of electrodermal reactions accompanying the changes of alertness in humans	Dorokhov, V.B., Dementienko, V.V., Koreneva, L.G., Markov, A.G., Shakhnarovitch, V.M., Zakharov, P.V., 1998, International Journal of Psychophysiology, 30, 1-2, p267.

These journal references, in addition to marketing literature provided by the manufacturer were used as information for the Scientific Criteria evaluation. The outcome of the evaluation is given in Appendix E.

The evaluation has identified that the research into the utility and application of Electrodermal Reactions (EDR) as a method of measuring levels of vigilance has been extensive. The literature provided by the manufacturer states that a combined total of 6500 test subjects over a 20 year research period to prove the technology. Experiments have been conducted to determine:

- Methods to differentiate EDRs from other components of electrodermal activity
- The differences of electrical resistance distribution over the surface of the hand
- Potential individual, gender or race differences in electrodermal activity
- The effect of ambient temperature and limb movement on the measurement of electrodermal activity
- The relationship between EDR and changes in vigilance and alertness
- The relationship between EDR and task performance



- The relationship between EDR and other measures of alertness (such as EEG)

Other key points to note from the evaluation are:

- The device uses bespoke algorithms to remove artefacts such as electrical activity from muscle movements, which indicates that it measures what it is supposed to operationally
- The research indicates that the device is an accurate predictor of a person's transition from a state of relaxation to drowsy sleep, and indicates a reduction in vigilance related to task performance
- The device has been benchmarked against other recognised physiological indicators of arousal, such as EEG
- The stated false alarm rates are most probably adequate not to distract drivers from their task

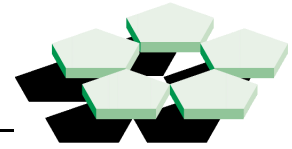
Unfortunately, information regarding the performance of the device on the railways was not available. A survey of drivers that use the device would help to establish the 'real world' validity of the device.

5.5 Conclusions of device evaluation

The Engine Driver Vigilance Telemetric Control System (EDVTCS) device has met all of the User Acceptance Criteria, and is the most likely candidate to meet the UK Railway Context Criteria. In terms of design development and actual use it is by far the maturest. It is anticipated that the MicroNod Detection System would have to overcome EMC issues, the locating of the sensor within the required range, before it would be considered. The effect of headwear on the measurement of head movement would also have to be determined. The ETS-PC Eye tracking system may also be suitable if integrated with an alarm/alert.

The Scientific Criteria evaluation of the EDVTCS indicates that extensive research has been conducted to prove the use of electrodermal reaction as a measure of vigilance. One method of assessing the validity of device in use would be to evaluate the device in-situ on the Russian Railways, and conduct interviews or surveys of drivers. High level experimental design issues for the testing and trialing of candidate devices are presented in Section 7.

The cost-benefits of a driver monitoring device are presented in Section 6.



6 Cost-Benefit Analysis

The purpose of this cost-benefits analysis was to gain an impression of whether a new driver vigilance device would provide significant safety benefits (in terms of reducing the number of SPaDs and other p-way incidents) over and above the financial investment required to implement the device.

The data for the cost-benefit analysis was collected during the first workshop meeting, and during a meeting convened between Railway Safety's Head of Standards Justification, Railway Safety's Principal Human Factors Specialist, and Quintec.

The product of the workshop was a set of high-level issues to be considered for a cost-benefit analysis of a new driver vigilance system. The Head of Standards Justification presented Railway Safety's adopted process for cost-benefit analysis (Reference 14) at the workshop. Appropriate methods for performing an analysis for the project were also discussed.

6.1 Process for Cost-Benefit Analysis

The key to Railway Safety's methodology for cost-benefit analysis is to identify and quantify the safety benefits of a proposed measure, identify and quantify the whole life costs and cost savings, and then compare the two outcomes. A reasonably practicable (or cost effective) outcome is if the net safety benefits of the measure are the same or greater than the net financial costs. Figure 4 presents the process flow for Railway Safety's Cost-Benefit Analysis method:

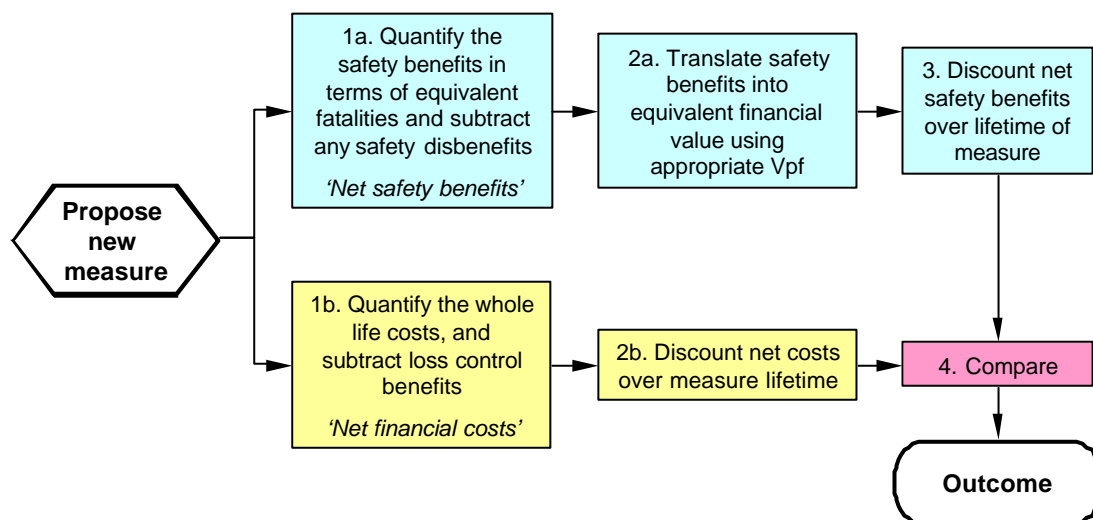
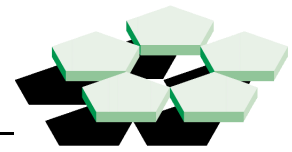


Figure 4: Process for Railway Safety's Cost-Benefit analysis method (from Reference 1)

Within the scope of this project it is not possible to perform a full cost-benefit analysis according to this method. Full cost-benefits generally take months of effort, drawing on the resources of many technical subject matter experts to determine and quantify benefits and costs

A qualitative assessment has been performed for the purpose of this project. The whole life cost categories were determined, and are given in Section 6.2. These categories were identified during the first workshop. An assessment of the potential device specific cost of a candidate is described.

A review of the Railway Safety Risk Profile Bulletin (2001, Reference 15) was performed and subsequently a case study analysis was conducted to determine the safety benefits.



6.2 Financial costs

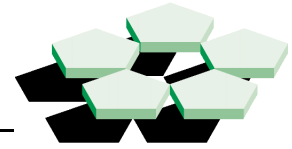
This section provides a description of the possible financial costs of implementing a new vigilance device and a description of the specific financial costs of the candidate device.

The life cycle periods for implementing a new vigilance device could be considered as:

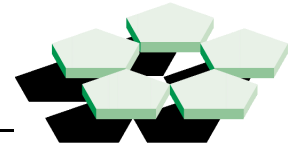
- Device assurance - where the appropriate certification is gained for the device
- Procurement - where the devices are purchased
- Installation - where the devices are installed into train cabs
- In-use - where the device is operated on the railways and maintained
- Disposal - where the device is phased out of service and replaced

The approach has been to give an indication of target system acquisition costs that can be employed to assess the candidate technologies. The cost issues and loss control benefits identified during the first workshop were categorised according to these life cycle periods, and according to whether they are device specific or device independent:

Financial cost	Description	Cost issues that may affect device feasibility
Device Assurance		
<i>Device independent</i>		
Scientific/Human Factors research and approval	The scientific validity of a device would have to be proved and approval gained from the appropriate bodies	-
'Concept of use' and identification of best practice procedures	A 'concept of use' includes all the operational aspects such as how the device may be interfaced with other safety devices and other human interface components, how a driver responds to repeated alarm, brake intervention, driver relief process etc. These have to be determined for successful device implementation	-
User community approval	The value of the device may have to be demonstrated to the unions and TOCs for approval	-
Vehicle approval and certification (VAB)	The device would require VAB approval for each class of train cab	-
Technical approval for signals (Route Acceptance)	The device would require approval for each route it is intended to be used on	-
Legislative approval	The device would have to be assessed for compliance with the HMRI's Rail Approval Regulations (RAR)	-
Changes to rule book and approval	The device may require changes to be made to the Rule Book	-
Procurement		
<i>Device dependant</i>		
Purchase of device	The cost to buy the required number of devices from the manufacturer	Cost will vary from device to device. An order of magnitude difference in device costs may affect the feasibility of procurement
<i>Device independent</i>		
Project management	Includes contract negotiations for purchase of devices, maintenance contracts, spares provisions contracts, training contracts etc.	-
Installation		



Financial cost	Description	Cost issues that may affect device feasibility
<i>Device dependant</i>		
Train cab modifications	The cost of designing and performing train modifications to accommodate the device, and to conform to VAB requirements	A device with several separate components may require a train cab to have more modifications than a device with one or two components. The size of the components would also be a factor
Fitting and testing of device in trains	The cost of fitting and testing the device into train cabs.	A device with several components may require more labour costs (more wiring up, more bolts/screws to fit etc.)
Training of maintainers and installers	The cost of training maintainers and device installers, including training needs analysis and course design. This should be offset against training costs for current devices	A device that that requires more complex and lengthy installation, or is itself complex in design and sophistication may require lengthier training, or even specific recruitment
Train 'out of service' costs	The cost of lost revenue due to trains taken out of service for equipment installation	A device that that requires more complex and lengthy installation may incur greater out of service costs
<i>Device independent</i>		
Survey of cabs	Surveys of each train cab would be required to determine the installation location of the device	-
Training (driver, installers, maintainers, and managers)	The cost of providing training on the use and management of the new vigilance device, including training needs analysis and course design. This should be offset against training costs for current devices	-
In-service		
<i>Device dependant</i>		
Maintenance	The cost to provide and manage maintenance activities for the new device. This should be off-set against costs to maintain current devices	A device that that requires more complex and lengthy maintenance may incur greater labour costs
Spares	The cost of procuring spares/replacements and the associated logistics costs. This should be offset against costs for current devices	Devices may have different components failure rates or different costs for the replacement components
'Out of service' costs due to routine maintenance	The cost of lost revenue due to trains taken out of service for equipment maintenance	A device that requires more complex and lengthy maintenance may incur greater out of service costs
<i>Device independent</i>		
Management and administration	The cost of managing and administering the operation and maintenance of the device. This should be offset against the cost of managing and administering the current device	-
Refresher training	The cost of providing refresher training to drivers	-
Avoided material damage costs of accidents	The avoided cost of property damage due to accidents. This is calculated by estimating the number of accidents avoided due to the new device	-
Avoided business interruption costs of accidents	The avoided cost of business interruptions due to accidents. This is calculated by estimating the number of accidents avoided due to the new device	-
Avoided third party liability costs of accidents	The avoided cost of accident claims for injury or property damage. This is calculated by estimating the number of accidents avoided	-



Financial cost	Description	Cost issues that may affect device feasibility
	due to the new device	
Avoided business interruption costs of incident (non-major)	The avoided cost of loss of revenue, profit, or disruption costs due to non-major incidents. This is calculated by estimating the number of incidents avoided due to the new device	-
Decommissioning		
<i>Device independent</i>		
Removal of devices	The cost of removing devices from train cabs	-
'Out of service' costs	The cost of taking trains out of service for the removal of the device	-
Disposal of devices	The cost of disposing or recycling device materials, in accordance with legislation.	-

Table 7: Device through-life financial cost issues

It is anticipated that the majority of costs would be incurred during device assurance and procurement. It may be possible to off-set some of the maintenance costs against the costs necessary to maintain current equipment. As none of the devices are currently used on the UK Rail network, and as it would be considered a safety critical device, the approval and assurance process may be long and complex.

The through-life costs and benefits assume that the device would be retrofitted to all or a selection of rolling stock. The analysis has not differentiated the costs of integrating the system within a new train, where the installation and out of service costs would be greatly reduced. This may affect the overall cost effectiveness of the device.

6.2.1 Device specific financial costs

The outcome of the device evaluation presented in Section 5.5 was that the Engine Driver Vigilance Telemetric Control Systems would be the most likely candidate for further assessment and possible implementation on the railways. Table 8 provides an overview of the possible financial costs of the device:



Financial Cost		Engine Driver Vigilance Telemetric Control System	
Procurement			
<i>Device dependant</i>			
Purchase of device	The device can currently be purchased for €6060 (equivalent to approximately £3600)		
Installation			
<i>Device dependant</i>			
Train cab modifications	A processor unit (20x10x50cm) and a display (20x10x30cm) would have to be located in the cab. The processor unit would have to be located 2m from the driver. A smaller processor is also available from the manufacturers		
Fitting and testing of device in trains	The processor and display would have to be fitted in the cab and also be connected together. The device would have to be tested with the sensor (located in the watch)		
Training of maintainers and installers	Not possible to comment on potential cost factors		
Train 'out of service' costs	Not possible to comment on potential cost factors		
In-service			
<i>Device dependant</i>			
Maintenance	The watch battery lasts for 1000 hours, which is approximately 125 duty cycles (assuming a duty cycle is approximately 8 hours). There are approximately 9700 train drivers, all of whom may require a watch. The first time to failure of the processing unit is 50 000 hours, which is approximately 5½ years. It is not known what level of preventative maintenance is required.		
Spares	This may depend on where components are manufactured. It is not possible to provide further comment on the potential cost factors		
'Out of service' costs due to routine maintenance	Not possible to comment on potential cost factors		

Table 8: Device financial comparison

The table in Appendix F gives the breakdown of all the stock types in use on the UK Rail network. The source of this information is given in Reference 16. The total number of rolling stock is calculated at 5077. This potentially equates to a maximum purchase cost of £36,554,400¹, assuming that each rolling stock has two cabs². This does not include other through life costs.

There may potentially be difficulties with retrofitting a large item such as the processing unit into train cabs. It is suggested that Railway EMC experts liaise with device manufacturers to assess the feasibility of using JS Co. NEUROCOM's smaller device, which uses CPU/electronics.

6.3 Safety Benefits

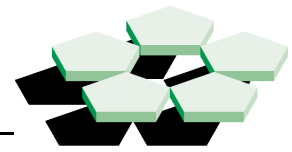
At this stage of the project, where a new vigilance device is merely being considered, it is difficult to say with certainty what positive effects a device may have on driver behaviour. Therefore, a simplified approach has been taken for describing the safety benefits of a new vigilance device. From the results of the technology information search, the safety benefit assessment assumes that the device will always prevent incidents (SPaDs and others) where the root or underlying cause is attributed to the driver being in drowsy or sleepy state.

According to Reference 14 the safety benefit of a new measure is found by calculating the effect the measure has on the number of expected equivalent fatalities per year. This is done by:

- Identifying the hazardous events affected by the measure, using the hazardous events given in the Risk Profile Bulletin, and the hazard precursors (causes)
- Evaluating the current level of risk associated with the relevant hazardous events and precursors

¹ £36,554,400 = Number of cabs x the cost of device per cab = 10154 x £3600

² It should be noted that new devices are not always retrofitted to aging rolling stock, the exemptions given to DRA may be a good example.



- Evaluating the effect the measure has on the frequency and consequence of each hazard and its precursor, and convert the effects into equivalent fatalities (e.f.)

A review of the Risk Profile Bulletin (Reference 15) was performed to identify the key hazardous events that would be affected by the introduction of a new driver monitoring device. One of the key objectives of the Risk Profile Bulletin is to:

'Enable ALARP (as low as reasonably practicable) assessments and cost-benefit analyses to be carried out (i) to assist in the decision making process regarding the merits of technical changes or modifications and new infrastructure investment and (ii) to assist in the development of safety justifications for proposed changes to Railway Group Standards'

6.3.1 Order of magnitude assessment of costs

It is possible to provide order of magnitude assessment of costs, and an estimate of the required safety benefits of a new vigilance device. Reference 14 provides a financial value for the prevention of fatalities. To determine the number of equivalent fatalities that have to be prevented by the device to ensure its cost effectiveness, the life time cost of the device is divided by the Value of a Prevented Fatality (VPF). The VPF is stated in the Railway Group Safety Plan and is given as £3.46 Million (for measures acting against multi fatality events, or measures reducing risk to an exposed group whose individual risk is near the upper limit of tolerability). Table 9 provides the calculations of the order of magnitude cost assessment. The life time costs are purely hypothetical, to provide an indication of the safety benefit required for each order of magnitude. These costs take into consideration the cost per cab for each of the whole life financial costs given in Table 8 (e.g. procurement, installation, out of service costs).

Hypothetical whole life cost (per cab)	Required risk reduction for device cost effectiveness (equivalent fatalities per cab per device lifetime)	Required risk reduction for device cost effectiveness (equivalent fatalities per device lifetime)
£10 000	$10,000/3,460,000 = 2 \times 10^{-3}$ e.f.	20
£20 000	$20,000/3,460,000 = 6 \times 10^{-3}$ e.f.	61
£50 000	$50,000/3,460,000 = 1.5 \times 10^{-2}$ e.f.	152
£100 000	$100,000/3,460,000 = 3 \times 10^{-2}$ e.f.	305

Table 9: Orders magnitude cost assessments

The figure of 10 154 cabs was used to calculate the equivalent fatalities per device lifetime (from Annex F, assuming that each rolling stock has two cabs). The number of equivalent fatalities that have to be prevented increases as the whole life cost per cab increases.

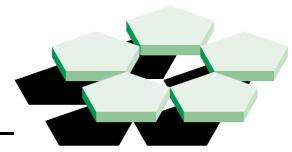
6.3.2 Safety benefit analysis

The key hazardous events in terms of percent contribution to overall railway safety risk that would potentially be affected by a new vigilance device are (identified from Reference 15):

- HET 1 Collision between two passenger trains (other than at platform)
- HET 2 Collision between a passenger train and non-passenger train
- HET 12 Derailment of passenger train
- HET 13 Derailment of non-passenger train

Where HET is 'Hazardous Event, Train Accidents'.

These four hazardous events contribute a little over 10% of the total risk to safety to public, passengers and staff (approximately 5% for HET 1 and HET 2, and approximately 5% for HET 12



and HET 13). It should be noted that the edition of the Risk Profile Bulletin review for this study does not include the implementation of TPWS.

The hazard precursor categories to HET 1 and HET 2 include:

- Driver fails to check signal aspect
- Driver fails to react to cautionary aspect
- Driver fails to locate signal
- Driver misjudges environmental conditions
- Driver misjudges train behaviour
- Viewed wrong signal
- Viewed correct signal but misread aspect
- Misread previous signal

The model provides a prediction of how frequent (events per train mile) these precursors will result in a SPaD and how they contribute to the risk of a fatality. Of all the categories, the new device would most likely reduce 'Failure to check signal aspect' and 'Driver failure to locate signals' SPaDs that are attributed to driver drowsiness or other losses of alertness. It should be noted that these two categories combined contribute to almost 40% of total risk for HET 1 and HET 2 for a passenger train SPaD.

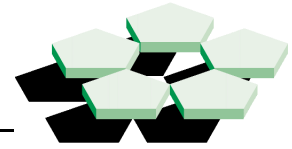
However, these figures include starting against signal (SAS) SPaDs which account for 17% of the total risk contribution. Table 10 gives the percentage of risk contributed by these hazard precursor categories and the potential risk mitigated by the device.

The hazard precursor categories to HET 12 and HET 13 include:

- Signal passed at danger leading to train derailment
- Running into items placed on the track by vandals leading to train derailment
- Running into trees leading to train derailment
- Overspeeding leading to train derailment
- Shunter errors leading to train derailment
- Severe braking/snatch leading to train derailment

Train derailment could either be passenger or freight train.

Of all the categories, the device would most likely reduce 'Overspeeding leading to train derailment', and 'Signal passed at danger leading to train derailment'. The causes of overspeeding would have to first be identified before any safety benefits are assumed, however a possible cause of overspeeding could be lack of vigilance by the driver. Table 10 gives the percentage of risk contributed by these hazard precursor categories and the potential risk mitigated by the device.



HET	Hazard precursor categories	%age precursor's risk contribution (to overall HET risk)	%age risk that could be mitigated by device (within precursor category)	%age of HET's total contribution to the total risk to safety on railways	%age of total risk to safety that could be mitigated by the device
1 and 2	Failure to check signal aspect	35.0%	18.0%	5.0%	0.9
1 and 2	Driver failure to locate signals	5.0%	5.0%	5.0%	0.25
12	Overspeeding leading to train derailment	1.3%	1.3%	3.2%	0.04
12	Signal passed at danger leading to train derailment	10.5%	2.4% ³	3.2%	0.08
13	Overspeeding leading to train derailment'	2.65%	2.7%	2.1%	0.06
13	Signal passed at danger leading to train derailment	6.65%	1.5% ⁴	2.1%	0.03
Sum of potential risk mitigated by the device (%age of total risk to safety) =					1.36%

Table 10: Risk contributions of hazard precursors and potential risk mitigated

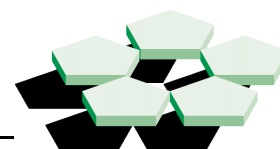
The figure for the total potential risk (to safety to the public) mitigated by a new vigilance device given in Table 10 is an estimate based on the figures given in the Risk Profile Bulletin. Using the predicted number of equivalent fatalities per year stated in the Risk Profile Bulletin, this figure corresponds to almost 2 equivalent fatalities per year. Over an estimated lifetime of 25 years, this equates to approximately 47 fatalities.

On reviewing the hazardous event precursors, the human error event precursors in these categories do not provide sufficient detail for the requirements of this safety assessment. It may be difficult to estimate the current risks associated with driver vigilance decrement from the current hazardous event model (Reference 15) without further analysis into the causes of individual SPaD events. Further investigation into the proportion of SPaDs that may be attributed to vigilance decrements may be required to assess the possible benefits of a new vigilance device.

Railway Safety's monthly SPaD report (Reference 17) presents figures on SPaDs according to their immediate cause category. From these category descriptions (and data taken from Reference 15), Table 11 gives the SPaD figures for 'Driver fails to check signal aspect' and 'Driver fails to react to cautionary aspect' immediate causes:

³ 2.4% = (18% + 5%) x 10.5% (Combined percentage risk contribution of SPaDs categories that could be mitigated by the device (given in HET 1 and 2) x Risk contribution of 'Signal passed at danger leading to train derailment' for HET 12)

⁴ 1.5% = (18% + 5%) x 6.65% (Combined percentage risk contribution of SPaDs categories that could be mitigated by the device (given in HET 1 and 2) x Risk contribution of 'Signal passed at danger leading to train derailment' for HET 13)



Immediate Cause	Percentage						
	96/97	97/98	98/99	99/00	00/01	01/02	02/03
Failure to check signal aspect	28%	27%	24%	30%	22%	27%	17%
Failure to locate signal	12%	8%	12%	5%	15%	13%	8%
Total (combined percentages)	40%	35%	36%	35%	37%	40%	25%
Not yet categorised	0%	6%	3%	1%	1%	9%	58%

Table 11: Immediate causes of SPaDs severity categories 3 to 8

'Driver fails to check signal aspect' and 'Driver fails to react to cautionary aspect' have typically contributed to over a third of all SPaDs of severity categories 3 to 8. This report accepts that no conclusions can be inferred as to the effectiveness of a new vigilance device to preventing or reducing the number of these SPaD categories. However, further investigation into the causes of the SPaDs attributed to these cause categories may provide further evidence for or against the implementation of a new driver vigilance device.

6.3.3 Case Studies

The purpose of conducting the case studies was to assess how a new driver vigilance device may have prevented previous SPaDs or minimised their affects.

Quintec were provided with 9 inquiry reports by Railway Safety. The reports represent a range of SPaD types. The references for the case study SPaD inquiries used are given in Table 12.

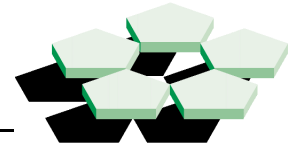
Reference	Date
01/RSR/094	November 2001
2001/RGW/083	October 2001
00/RSR/035	June 2001
01/RSR/052	July 2001
01/RMI/301	August 2001
2001/RGW/060	June 2001
2001/RGW/052	June 2001
2001/RGW/091	October 2001
01/RSR/115	December 2001

Table 12: References for Case Study SPaD inquiries

Each inquiry report was reviewed and the conclusion section identified. These are presented in Appendix G. It should be noted that details such as driver names, signal numbers and other identifying information has been removed to maintain the confidentiality of the reports, which are not in the public domain. Each conclusion section described the causes of the SPaD event under two or three of the following categories:

- Root
- Basic
- Underlying
- Direct
- Contributory
- Immediate

These were reviewed for causal factors such as driver tiredness. Of the nine case studies, one (Case 3) could be attributed to a driver disregarding a caution and a danger signal due to



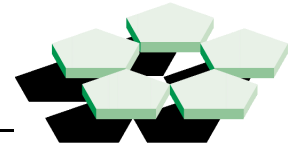
drowsiness. The train, however, was not fitted with the current driver vigilance device, making the evaluation of the potential beneficial effects of a new device difficult.

Case studies are an effective and fairly simple method of determining the effectiveness of a new measure, such as a new driver vigilance device. Unfortunately, it is not possible to draw any positive conclusions from the inquiry reports provided. However, if the causes of the SPaDs given in the nine SPaD reports assessed for the case studies are representative then there may be less probability of a safety benefit than suggested in Section 6.3.2.

6.4 Conclusions of Cost-Benefit Analysis

It was not possible within the scope of the research project to perform a full cost-benefit analysis of a new device, however whole life financial cost were described for each stage of the device's life cycle. It is anticipated that the majority of costs would be incurred during device assurance and procurement. Overall cost effectiveness may depend on whether the device is retrofitted to current rolling stock, or whether it is implemented only in future rolling stock. Safety benefits may differ according to the type of line or type of service (freight, high speed, suburban) that the device may be implemented on. Future cost-benefit analyses should differentiate the costs and benefits of each of these factors.

It is anticipated that the safety benefits of TPWS will reduce the severity of the consequences of SPaD incidents, by reducing the number of SPaDs on signal overlaps. This may reduce the potential benefits of a new monitoring device. The types of incidents that use of the device would potentially avoid should be researched further to identify the added safety benefits above those provided by TPWS. More detailed human error event precursors may be required to fully identify the potential safety benefits of a new device, or a review of a larger sample of SPaD reports.



7 Experimental Design Characteristics

The purpose of this section is to present a 'high-level plan' for the implementation of the device including:

- Testing of user issues
- Testing of cab fit issues
- Testing of legislation issues
- Testing of EMC issues

In addition, this section discusses the experimental design requirements that may be required to prove the scientific feasibility of a new vigilance device, including:

- Desired outcomes for the tests including industry acceptance
- Required fidelity levels of tests
- Test scenario controls
- Test measures and test criteria
- Participant groups and numbers
- Practical aspects of tests
- Ethical consideration

The high-level implementation plan and required characteristics for experimental design were discussed and developed during a working group workshop convened by Railway Safety. The attendees at the meeting included EMC, Signalling, Vehicle Installation, Operations, Project Management and Human Factors experts from Railway Safety.

7.1 High level implementation plan

The purposes of developing a high-level implementation plan were to:

- Determine the 'levels' at which device approval is required
- Determine the tests and preconditions necessary for device approval
- Determine the methods required for achieving approval

The process for device approval and implementation was identified during the workshop and is represented in Figure 5.

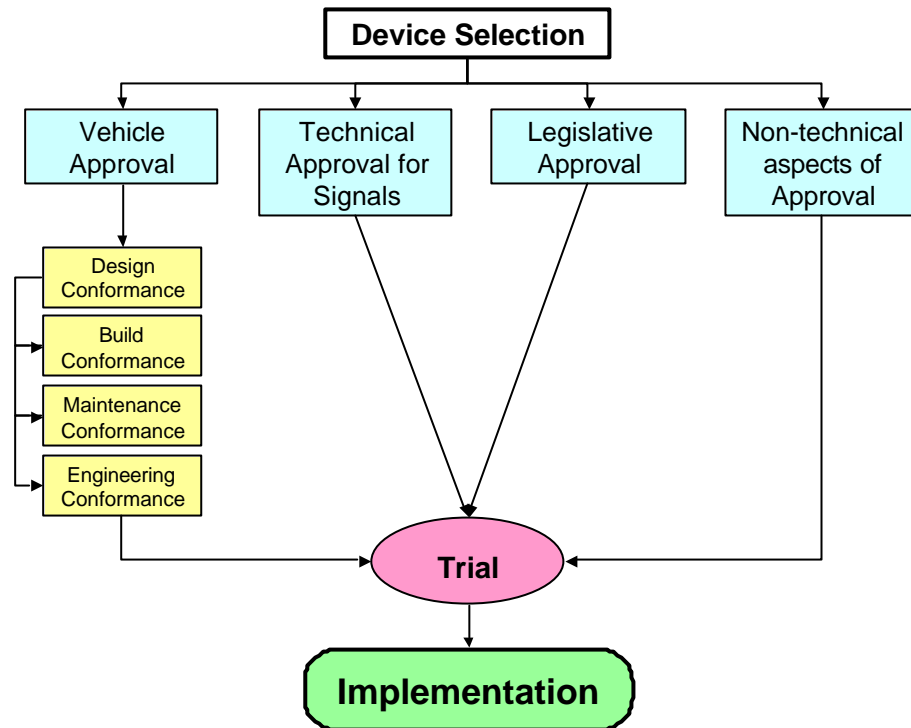
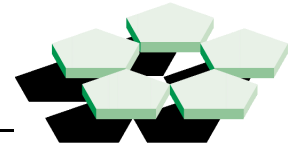


Figure 5: Possible process for device approval

Once a device is selected then there are a number of levels of approval that have to be met before the device can be accepted for use on the railway. These levels are typical for any safety critical device. The outcome of the approval process would be to trial the device on a part of the rail network. Each level of approval would be performed in parallel.

7.1.1 Vehicle approval

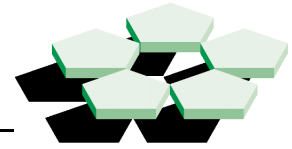
The process for vehicle approval would be conducted by 1 of the 6 or 7 Railway Safety approved Vehicle Acceptance Boards (VABs). The VABs would assure that a device being installed into a train cab complies with the railway group standards.

For EMC and noise standards, approval would have to be gained for each type of rolling stock and potentially each cab end. This is due to the different noise environments, and different electrical environments. EMC and noise levels would have to be demonstrated in-situ, which may require the equipment to be trialed and measured on a test track. Mis-use of the device would also require thorough investigation and testing.

The process steps for VAB approval (as shown in Figure 5) are:

- Design Conformance
- Build Conformance
- Maintenance Conformance
- Engineering Acceptance

Design Conformance is the process by which the design of the equipment is measured for conformance against the relevant design standards. It also ensures that the installation of the equipment is correct. Interfaces with the train, the control device location, the display device location related to the device, and the audio and visual alarms are compared to the design standards. Furthermore, the equipment is considered with respect to its interaction with the wider



system. This could be the method of communication used for equipment components, frequencies and wavelengths, and EMC compatibility. The first exercise for Design Conformance would be to determine whether standards exist for driver vigilance devices and whether they are appropriate.

Build Conformance is the process by which the installation of the equipment is checked, prior to and during installation. It is to assure that modifications to the train are performed in accordance with the design, to ensure that safety has not been compromised, and that the required standards have been maintained.

Maintenance Conformance is the process by which the equipment maintenance requirements are assessed. This includes ensuring that planned inspection, maintenance, and overhaul periods are adequate, that maintenance does not impact other systems of maintenance, that the system can be maintained, and that the equipment is functional.

Engineering acceptance is the final stage in the vehicle equipment approval process. An independent engineer reviews the design, build and maintenance of the equipment and provides a certification on successful acceptance.

7.1.2 Technical approval for signals

Route acceptance would be required for the equipment. The infrastructure controller has responsibility for the route acceptance process. It can be as much of a problem to gain route acceptance as vehicle acceptance, since line side equipment is variable with each route.

The key to route approval is to ensure that the device will not generate spurious signal aspects. The driver vigilance device may not present a large problem, as the device would not have a direct physical link to the rails. Signalling equipment has an electrical component in the running rails. The radio propagation of the equipment would also have to be taken in to consideration, especially if the device uses telemetry to transfer data from sensors to a processor unit. Bluetooth technology could be suitable for devices that require radio transfer of data, as the frequencies and signal power used are unlikely to disrupt signalling equipment.

7.1.3 Legislative approval

New or altered railway work may need approval under the Railways and Other Transport Systems (Approval of Works, Plant and Equipment) Regulations 1994. This approval is given by Her Majesty's Railway Inspectorate for the Health and Safety Executive. The HMRI has a statutory duty to consider, inspect and (if appropriate) approve proposals for new or altered railway "hardware". Approval is required for all new traction or rolling stock, the reintroduction of old traction or rolling stock and for alterations to existing traction or rolling stock if any of these actions could effect safety. The HMRI publication 'Guide to the approval of railway works, plant and equipment' provides information how to meet the railway regulations. Requests for consents have to be made to the HMRI before new equipment is brought into use.

7.1.4 Non-technical aspects of approval

Non-technical aspects of assurance include scientific proving, training, procedures, management and rules.

It was stated at the workshop that the current Rule Book does not cover the use of the Driver Vigilance Device; only how to deal with non-working devices. If a new vigilance device was introduced it would be up to the individual Train Operating Companies (TOC) to devise its own operating practices and instructions to drivers. This would then be part of the configuration of the vigilance device, for example threshold levels, indications given, and how the driver would or should respond to the information or alarms provided.

Railway Safety would firstly mandate what a new vigilance device would have to achieve. They would provide guidance on vigilance threshold levels, the types of measures to use, and



circumstances and procedures for taking drivers 'out of service'. The TOCs would then be allowed to select the most appropriate device, procedures, and rules for their own operating circumstances. It was stated that a paragraph would be required in the Rule Book on the new vigilance device, and a couple of paragraphs required for the medical competency book regarding vigilance, vigilance monitoring and the effects of reduced vigilance.

The implications for Railway Safety of providing guidance on vigilance monitoring devices is that they would have to provide evidence of what acceptable levels of vigilance or arousal are. This would be the case for each measure of vigilance or arousal that is recommended by Railway Safety.

The issues associated with the OTMR were discussed. It was stated that the device may take longer to implement and gain approval if it was linked to the OTMR. Firstly the OTMR may require modifications, which would mean the modification of the OTMR design standard. Further work would also be required to examine the utilisation of the data recorded from DVD to OTMR, the safety benefits and performance benefits. Data recording may make it harder to gain approval from the Users.

The device may require cultural changes in the Industry for it to work effectively.

7.1.5 Trialing a device

The requirements and approval necessary to trial a device on the railways was discussed. Certain levels of approval would be required to trial a device on the railways. A limited period temporary non-compliance would be required. The train operating company would have to apply for this. Depending on the trial environment, a risk assessment would be required. If the trial were to run on a Railtrack line, it would require a HAZOP and risk assessment. GART 6001 (Railway Group Standards Change Procedures) and 6004 (Temporary Non-compliance with Railway Group Standards) describe the derogation process and temporary non-compliance process. A trial run on a test track may not require such approval.

7.2 Experimental design

The process of testing and validating the device was discussed during the workshop. It was agreed that a device would be trialed in three stages:

- Lab-based tests
- Simulator trial
- Test track trials

Testing and validating the device would require the consideration of the following experimental design characteristics (Figure 6):

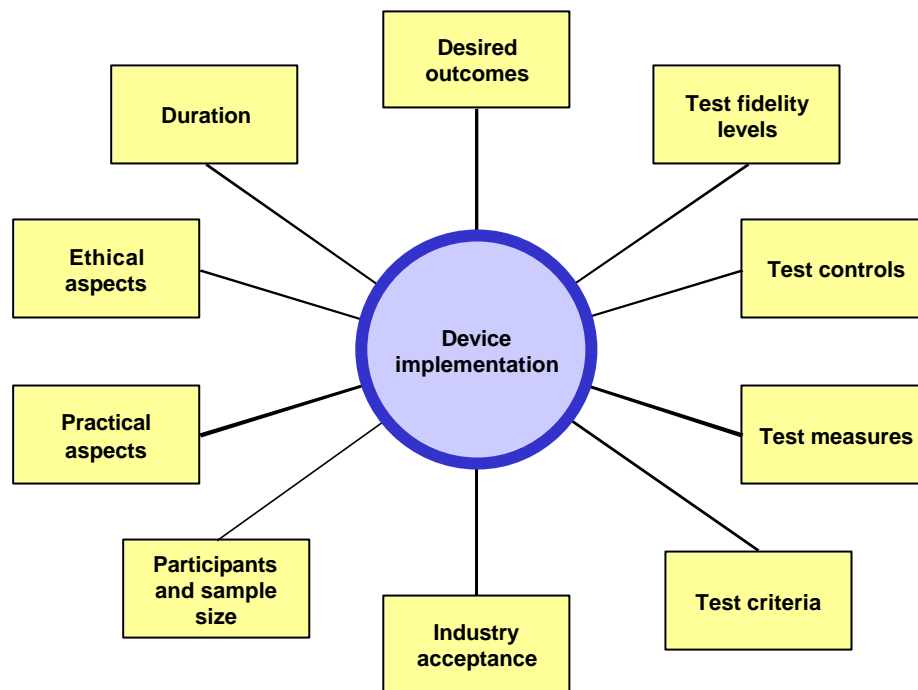
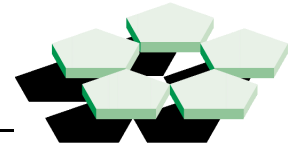


Figure 6: Experimental design characteristics

These are described in further detail below:

- **Desired outcomes** - These are the required outcomes for each trial stage to ensure that the device is suitable for use on the railways.
- **Fidelity level** - The level of sophistication and realism applied to an experiment, trial or training exercise. These levels range from paper-based, PC based, part-task simulator, full-motion immersive simulator, to 'real world'.
- **Test controls** - The characteristics of an experiment or trial that you want to keep constant or change. In this context, possibly Route, Rolling Stock, Environment, Drivers, Vigilance device would be considered as controls.
- **Test measures** - The characteristics of the experiment or trial that you want to measure. These determine the effect or performance of the Test controls. In this context, possibly device alerts, SPaD events, 'false-alarms' would be considered as measures.
- **Test criteria** - These are criteria that the device has to meet during testing to ensure that the device provides the desired effects.
- **Industry acceptance** - These are issues that relate to confidence within the Industry
- **Test participants and sample size** - The type and number of participants required for a successful trial. Participants could be chosen according to age, experience, 'track record', TOC, or level of training.
- **Practical aspects** - These include the funding of any experiments (equipment, experimenters and participant's time), reporting and arranging of experiments.
- **Ethical aspects** - These include ensuring the health and safety of participants and experimenters is maintained during experiments.
- **Duration** - This concerns the duration of individual tests, the duration of experiments and the duration of studies. For example, driver duty cycles should be considered for the duration of experiments.
- **Experimental design** - This includes selection of controls, measures, fidelity, and sample. It also includes selection of statistics to use and how tests are allocated to participants.



The following sections describe the stages of trialing and testing the device to determine its scientific feasibility.

7.2.1 Lab based tests

A lab-based test should be performed to validate the reliability and repeatability of the device, and to ensure that the device measured what it is supposed to. This would act as an independent assessment of the device. It would not be necessary to use actual drivers for the test, and standard laboratory vigilance tests could be used. High levels of fidelity would not be required for the lab test.

7.2.2 Simulator tests

A simulator test would use a high fidelity train simulator to assess the validity of the device in the context of train driving tasks. Different rolling stock types, routes, environmental conditions could be tested. In addition, train drivers would be used to perform the tests. The duration of the train duty cycle would need to be replicated to best simulate possible reductions in performance over time. Worst case routes and rolling stocks could be determined and replicated in the simulation environment, for example, routes that were regarded as problematic in terms of drivers remaining vigilant.

7.2.3 Test track trials

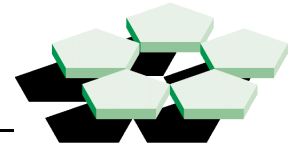
Trialing of the device on a test track may be required to provide assurance to Train Operating Companies and Users that the device works in a real train operating environment. There are circular test tracks available for use in the former Czechoslovakia.

7.2.4 Other experimental design issues

The effectiveness of a new device may have to be benchmarked against the current driver vigilance device during a simulator trial. This activity may be required for the Cost-Benefits case.

During the workshop it was suggested that any device should be benchmarked against recognised and reliable measures of vigilance. One such measure could be EEG recordings, taken from brain activity as it is a recognised indicator of arousal. Furthermore, it was suggested that the thresholds of arousal may need to be investigated further, so that they are suitable for railway operations. The testing of a device in a simulator would enable appropriate thresholds of arousal to be identified.

Railway Safety are currently investigating the possibility of procuring a train simulator to assist with performing experiments, tests and trials. Such a simulator would be ideal for testing a new driver vigilance device.



8 Outcomes of the Research

The purpose of this section is to present the conclusions from the analysis and research conducted during the course of the research, and the resulting recommendations.

8.1 Conclusions

The study identified thirteen devices that could potentially be used to monitor driver readiness to respond to signal aspects and trackside information. Of these, ten were evaluated against feasibility criteria developed during workshops. All of these devices measured a component of driver arousal, or the physical and behavioural manifestations of low arousal. None of the devices could be considered suitable for monitoring driver attention allocation or distractions. Three devices were identified as being suitable for use by drivers and within the constraints of the UK Railway infrastructure.

One device, EDVTCS, was considered mature in terms of design development and actual use, and would be the most suitable candidate to recommend for implementation on the railways. The MicroNod Detection System and ETS-PC Eye tracking system could also be considered as suitable, pending the resolution of EMC issues (MicroNod) and modifications to the design (ETC-PC). However, neither of these devices are currently used on railways.

The exercise to identify the types of financial costs to implement a device found that the majority of costs would be incurred during device assurance and procurement. The order of cost magnitude assessment found that the number of equivalent fatalities that have to be prevented increases as the whole life cost per cab increases. When compared to the estimated safety benefits (Section 6.3.2), the through-life costs of the device would have to be less than £20 000 (per device per cab) for the device to be cost effective. The safety benefits analysis found that the data provided in the Railway Risk Profile Bulletin was insufficient (interms of detail) to accurately calculate the potential safety benefits. In addition, the constraints of the project meant a full and thorough cost-benefit analysis could not be performed. The case study of nine SPaD reports (Section 6.3.3) found only one report that could be attributed to driver drowsiness. Most of the others were attributed to some form of distraction.

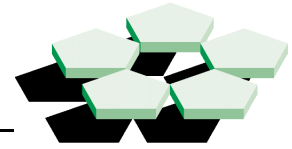
The process for device assurance was identified during a workshop with subject matter experts. Several areas and levels of assurance were identified. The assurance process could possibly be lengthy (i.e. years), pushing any in service date back to the point where full train protection systems and in-cab signalling may be implemented. This may adversely affect the cost-benefits of the device.

With the implementation of TPWS (and full train protection and in-cab signalling), and the safety benefits they provide, may reduce the potential benefits of a driver monitoring device. A device could possibly provide safety benefits. The study has shown the availability of devices that provide reliable measures of arousal, but the prevalence of drowsiness related incidents would have to be investigated and quantified before a full cost-benefit assessment could be performed. The evidence from this study also suggests that the extent of the assurance requirements may dissuade the Industry from investing in the implementation of a device.

8.2 Recommendations

To enable Railway Safety to decide whether the implementation of a new driver monitoring device would be cost effective and practical, the following key actions need to be taken:

1. Estimate the cost of retro-fitting devices into train cabs. This could be performed during a workshop using subject matter experts and rolling stock manufactures.
2. Investigate the prevalence of drowsiness-related SPaDs and other 'risk to safety' incidents. A targeted analysis of individual SPaD reports (using a larger, more representative sample)



could be performed and complimented by an analysis of CIRAS railway data. The beneficial costs of a device should also be estimated.

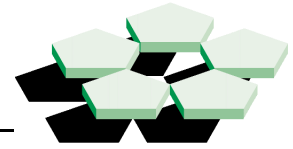
3. Investigate the cost-effectiveness of implementing a device on different categories of routes (e.g. freight, high speed or suburban), or different TOCs.
4. Identify the full assurance process required for device implementation and estimate the possible associated costs.
5. Identify whether the current railway standard for vigilance devices would be appropriate for a monitoring device.

If Railway Safety decide to further the investigation of promoting the use of the maturest driver monitoring device, it is recommended that the following actions are taken:

1. Further evaluation of the EDVTCS device should be conducted in situ, to learn from current device users. This will assist in establishing the 'real world' validity of the device. Furthermore, a study of the safety benefits gained by the device's implementation in Russia could be performed.
2. A device should be purchased for use in laboratory or simulator studies to confirm the scientific validity of the device, to understand more about the effects of alerting drowsy drivers, and to investigate the possible benefits of providing drivers with an indication of their arousal level. The effects of alarm signal characteristics on alerting drivers should be investigated.
3. An appropriate, representative and practical benchmark for arousal/alertness should be identified, either through literature search or by experimentation and trialling. This should be aimed at providing a standard and rulebook entry for driver monitoring devices. In addition, appropriate levels of arousal/alertness for train driving task should be identified.
4. Investigate the EMC properties of the device and determine whether the integrity of the rolling stock and signalling system would be affected by, or affect the device.
5. Investigate the User Acceptance and Railway Context implementation issues given in Sections 4.1 and 4.2.

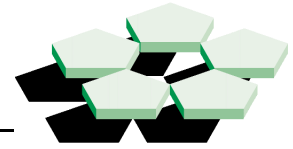
Further recommendations are made as a result of the study:

1. Railway Safety should investigate the possibility of expanding the human error cause categories for the Risk Profile Bulletin. This could be performed using fault tree analysis techniques, SPaD report data and general human reliability data. The study found the data in the report useful, but not detailed enough to provide a clear indication of human failure types, and associated failure rates or error probabilities.
2. Investigate how overt indicators of visual attention, such as gaze direction and fixation time can be used to determine incidences of driver distraction. Typical patterns of gaze direction for track monitoring (between signals), and visual search (before signal is in view) could possibly be identified. This would supplement current research into visual attention. Eye tracking technologies could be programmed to identify typical and non-typical (distracted) eye movements. This research should be aimed at understanding visual attention for future in-cab signalling systems as well as current lineside signalling. These could be linked to the baselining of arousal/alertness measures and levels.

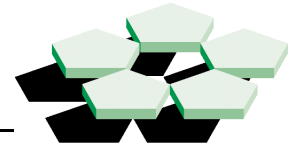


Appendix A: Device database

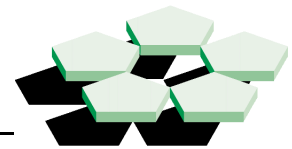
Company owning IPR	Bristol University
Name of device	Eye tracker and steering wheel sensor
Patent number	
Contact company or organisation	Department of Physiology
Contact first name	Dilwyn
Contact surname	Marple-Horvat
Postal Address	University of Bristol
Town or City	Bristol
County or State	
Country	UK
Phone number	44 (0)117 928 7804
Fax number	
Email	pys-acc1@bris.ac.uk
Web site	www.bris.ac.uk/Depts/Physiology
Source of information	Guardian newspaper, www.guardian.co.uk/uk_news/story/0,3604,665413,00.html This device uses ASL's eye tracking technology
Type of vigilance measured	
Physiological variable measured	
Vigilance thresholds	
Invasiveness	
Device response to reduced vigilance	
Method of calibration	
Set up times	
Set up requirements	
Frequency of calibration	
Size cms	
Power requirements	




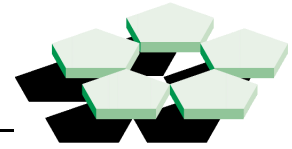
Company owning IPR	Bristol University
Name of device	Eye tracker and steering wheel sensor
Cost per unit	
Maintenance requirements	
Peripheral equipment required	
Environment required for operation	
Training required	
Availability	
Has the device been approved?	
Has the device been proved of tried?	
Which industries has it been used in?	Road transport



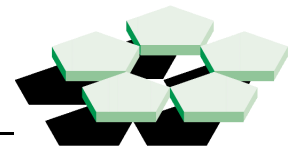
Company owning IPR	Future of Technology and Health
Name of device	Eye Tracking Alertness monitor
Patent number	No patents or patents pending at this time
Contact company or organisation	Future of Technology and Health, LC
Contact first name	Jeffrey
Contact surname	Bishop (Director of R&D)
Postal Address	337 E. College Street
Town or City	Iowa City
County or State	Iowa
Country	USA
Phone number	319/354-7652
Fax number	561/619-8059
Email	bishop@futh.com
Web site	www.alertdriver.com www.futh.com
Source of information	Google, internet search, key word: vigilance monitoring
Type of vigilance measured	Drowsiness/alertness
Physiological variable measured	Eyelid droop, pupil occlusion, eyelid closure
Vigilance thresholds	The threshold is if the eyes remain closed more than 1.5s, or if a sustained pupil occlusion (eye closure/eye lid droop) of greater than 1.5s is detected.
Invasiveness	Not invasive
Device response to reduced vigilance	An audible alarm is presented to the user in response to a state of reduced vigilance. Alarm is computer generated, and can be an amplified human voice or a 'beeping' alarm. The alarm is cancelled when fully open eyes are detected, or after a programmed period of time passes.
Method of calibration	Automatic calibration of eye measurement upon system startup. Calibration takes only a few seconds
Set up times	Set-up is estimated at a few minutes.
Set up requirements	Camera installation with subject's face in field of view. A feedback image is provided on the laptop to aid system set-up. Following set-up, the system can be started and operated without the need to open up the laptop. The camera is currently mounted using velcro. The sensor should be positioned approximately 60cm away from the user.
Frequency of calibration	automatically recalibrates as needed when tracking is lost
Size cms	See below




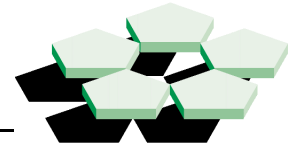
Company owning IPR	Future of Technology and Health
Name of device	Eye Tracking Alertness monitor
Power requirements	Not known
Cost per unit	\$500
Maintenance requirements	Failure rates, reliability and maintenance requirements are still being investigated
Peripheral equipment required	Sensor - 5cm x 6cm x 5cm, 100g. Processing unit (environmentally hardened, pentium laptop computer) - 4.25cm x 18.5cm x 22.5cm, 1.5kg.
Environment required for operation	The device works with spectacles and contact lenses, but not sunglasses.
Training required	Not known
Availability	The device is not yet commercially available
Has the device been approved?	The device has not, as yet, been designed to any BSI, ISO, ANSI or EN standards
Has the device been proved of tried?	The device has been used in laboratory studies only.
Which industries has it been used in?	
Photographs	



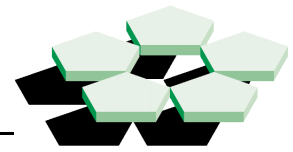
Company owning IPR	Advanced Brain Monitoring Inc
Name of device	ABM Drowsiness Monitoring Device (DMD)
Patent number	US Patent USSN 09/245,784 'Portable EEG Electrode Locator Headgear'. Patent pending on sensors (to be awarded 07/02)
Contact company or organisation	Advanced Brain Monitoring Inc
Contact first name	Chris
Contact surname	Berka (Company CEO)
Postal Address	2850 Pio Pico Drive, Suite A
Town or City	Carlsbad
County or State	California
Country	USA
Phone number	(760) 720-0094
Fax number	
Email	chris@b-alert.com
Web site	www.b-alert.com
Source of information	Google, internet search, key word: vigilance monitoring
Type of vigilance measured	Drowsiness/alertness
Physiological variable measured	EEG
Vigilance thresholds	Onset of 'drowsy' EEG readings
Invasiveness	The electrodes dispense a small amount of conductive gel.
Device response to reduced vigilance	The device presents an auditory warning to the driver in the event of a drowsiness state being detected. The effects of different types of feedback on performance is currently being researched by the company.
Method of calibration	Calibration only required for initial use
Set up times	See above
Set up requirements	One-time 15-minute calibration required for a new user. Cap application is 3-5 minutes.
Frequency of calibration	Calibration only required for initial use
Size cms	Sensor head set is 6 x 12.5cm
Power requirements	Sensor head-set 2 x AAA batteries
Cost per unit	\$500 (October 2001) Fee covers equipment, sensors, and a variety of reporting and tracking options
Maintenance requirements	According to literature, batteries last 8 hours in head set. The sensors should be cleaned (and refilled) after about 48 hours of




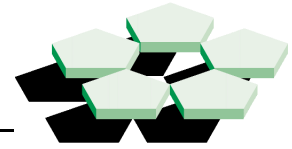
Company owning IPR	Advanced Brain Monitoring Inc
Name of device	ABM Drowsiness Monitoring Device (DMD)
	use. The sensors were designed as disposables, however, at present manufacturing volume they are prohibitively expensive (~\$4.00). With increased production (100,000 per run) the cost per sensor will drop below fifty cents, making the disposable option more viable. Failure rates are not yet available.
Peripheral equipment required	Caps come in four different sizes, according to head size. The workstation transceiver unit is required to compute the EEG data.
Environment required for operation	Head set has to be within 20ft of the processor/analyser. The device transmits at a radio frequency of 915kHz.
Training required	Not clear from web site
Availability	Available now to buy, although production version still in testing
Has the device been approved?	The devices are currently being designed and will be manufactured following U.S. manufacturing standards
Has the device been proved of tried?	The technology has been proved in laboratory trials and car/truck driving simulators and has been validated with other measures of vigilance. Extensive research has been performed.
Which industries has it been used in?	Not used yet
Photographs	



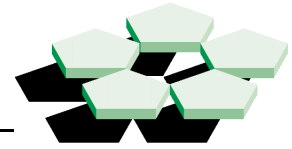
Company owning IPR	Michael Myronko
Name of device	Photo Driven Alert System (Patent 0208247.7)
Patent number	No patents applied for. Permission given to publish information was granted by Mr Myronko
Contact company or organisation	
Contact first name	Michael
Contact surname	Myronko
Postal Address	117A Northgate
Town or City	Basford
County or State	Nottingham
Country	UK
Phone number	0115 970 3837
Fax number	
Email	mmyronko@thyssen-gb.com
Web site	
Source of information	Railway Safety initially made contact with Michael
Type of vigilance measured	Alertness
Physiological variable measured	Blink rate
Vigilance thresholds	The threshold is if the user exceeds a blink rate of 1 blink per 4 - 6s.
Invasiveness	Partially invasive. Device has to be worn around the ear.
Device response to reduced vigilance	Provides an auditory alert to warn of danger.
Method of calibration	None required
Set up times	2 minutes
Set up requirements	The device automatically switches on when plugged in. The device requires two minutes on stand-by to adjust to working temperature of the sensor. An audible 'tick' is heard when the device is responding. Once set up is complete the alert is activated
Frequency of calibration	N/A
Size cms	See photo
Power requirements	9 v PP3 battery or equivalent
Cost per unit	£300 @ prototype stage
Mainenance requirements	-





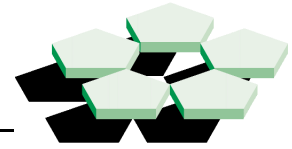
Company owning IPR	Michael Myronko
Name of device	Photo Driven Alert System (Patent 0208247.7)
Peripheral equipment required	Small housing for amplifier, metal detector, and sounder. 4 x 8cm. Tracker device is connected to the sounder via a cable.
Environment required for operation	Preferably airconditioned.
Training required	Setting up and operation training
Availability	Currently a prototype
Has the device been approved?	Tested in a motor vehicle, but has had no formal approval
Has the device been proved of tried?	No
Which industries has it been used in?	None
Photographs	



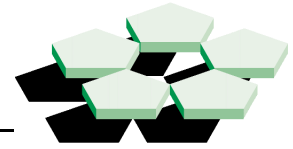
Company owning IPR	J-S Co. NEUROCOM
Name of device	Engine Driver Vigilance Telemetric Control System (EDVTCS), 3rd Generation
Patent number	Patent of Russian Federation No. 2025731
Contact company or organisation	MSTS S.A.
Contact first name	Marina
Contact surname	Pashkina (Chairwomen)
Postal Address	42, rue de Clausen
Town or City	Luxembourg BP 531
County or State	
Country	Luxembourg
Phone number	00 352 42 31 18 or mobile 3247 624 9784
Fax number	00 352 421 680
Email	marina.pashkina@msts-sa.com
Web site	www.msts-sa.com
Source of information	Railway Safety provided information and contact details about the EDVTCS system.
Type of vigilance measured	Alertness
Physiological variable measured	Electrodermal activity (galvanic skin resistance, GSR)
Vigilance thresholds	The EDVTCS is able to predict, using a derivative of electrodermal activity, when a driver begins to loose concentration and alertness. At this point, the alarm sounds
Invasiveness	Not invasive
Device response to reduced vigilance	Device presents an auditory alarm to the user a few tens of seconds before the level of alertness decreases to a critical value. The driver has to cancel the alarm within a set period of time else the brakes are applied. Once the alarm has been cancelled, the device again measures GSR.
Method of calibration	The watch automatically callibrates itself when switched on. The device assumes the driver is in a relaxed state when being callibrated.
Set up times	Callibration takes 10-20sec.
Set up requirements	Currently, the driver is required to don the watch and ensure that the electrodes make good contact with the wrist. Once in the cab, the driver has to then switch the watch on. The driver would then switch the main unit on. The driver would check that the radio signal receiver is illuminated. The devices is also tested prior to a train journey. This is performed using a handheld tester box.
Frequency of calibration	Callibration occurs everytime the watch is switched on, therefore should only occur once during a driver's shift



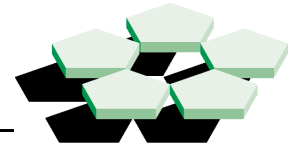
Company owning IPR	J-S Co. NEUROCOM
Name of device	Engine Driver Vigilance Telemetric Control System (EDVTCS), 3rd Generation
Size cms	see Equipment Required
Power requirements	50, 75 or 110 volts for main unit
Cost per unit	6060 Euros.
Maintenance requirements	Watch batterys last for 1000 hours (approx 40 days)
Peripheral equipment required	Wrist watch, a processor unit (20x10x50cm), display (20x10x30), tester box.
Environment required for operation	The range of the transmitter device is 2m. The radio frequency of the device communication is 17000MHz. The power output of the radio signal is 6 mcW
Training required	
Availability	Currently available
Has the device been approved?	The device has been approved by the Ministry of Transport of Russia
Has the device been proved of tried?	The device has been in use for 5 years on the Russian Railways and has been used in road transport for long-haul trips and transporting hazardous goods
Which industries has it been used in?	Railway, Road transport
Photographs	 



Company owning IPR	Part of the EU's Information Society Technologies (IST) research programme
Name of device	Hypovigilance Diagnosis Module (HDM) and Driver Warning System
Patent number	
Contact company or organisation	Centre for Research and Technology Hellas, Hellenic Institute of Transport
Contact first name	Evangelos
Contact surname	Bekiaris
Postal Address	6th Km Charilaou-Thermi Road
Town or City	Thermi-Thessaloniki
County or State	57001
Country	Greece
Phone number	+30 310 241078
Fax number	
Email	trnspon@compulink.gr
Web site	
Source of information	Google, internet search, key word: vigilance monitoring
Type of vigilance measured	
Physiological variable measured	
Vigilance thresholds	
Invasiveness	
Device response to reduced vigilance	
Method of calibration	
Set up times	
Set up requirements	
Frequency of calibration	
Size cms	
Power requirements	
Cost per unit	
Mainenance requirements	




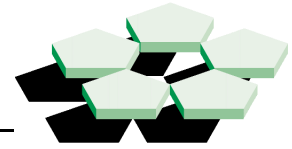
Company owning IPR	Part of the EU's Information Society Technologies (IST) research programme
Name of device	Hypovigilance Diagnosis Module (HDM) and Driver Warning System
Peripheral equipment required	
Environment required for operation	
Training required	
Availability	
Has the device been approved?	
Has the device been proved of tried?	
Which industries has it been used in?	



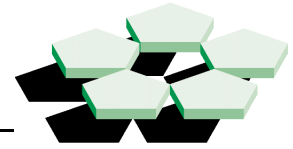
Company owning IPR	Australian Coal Association Research Programme (ACARP)
Name of device	Device for monitoring haul truck operator alertness
Patent number	
Contact company or organisation	ARRB Transport Research Ltd
Contact first name	Nick
Contact surname	Mabbott
Postal Address	500 Burwood Highway
Town or City	Vermont South
County or State	Victoria
Country	Australia
Phone number	+ 61 3 9881 1555
Fax number	+ 61 3 9887 8104
Email	nickm@arrb.org.au
Web site	
Source of information	Google, internet search, key word: vigilance monitoring
Type of vigilance measured	Alertness and fatigue
Physiological variable measured	Decision response reaction time task
Vigilance thresholds	Reduced reaction time deemed to be slower than one standard deviation below the predetermined baseline.
Invasiveness	Only in terms of adding a secondary task
Device response to reduced vigilance	The device responds in three ways. Firstly, the frequency of the reaction time test increases, secondly an alert is presented to the driver, and thirdly the supervisor is notified of the drivers state.
Method of calibration	The key is touched against a receptacle on the device to activate the fatigue monitoring device.
Set up times	Less than 5 seconds
Set up requirements	Reaction time baselines are determined for each individual driver. The driver is required to log onto and enable the device with their own personal 'touch key'. The touch key carries the drivers specific code. The device then loads up the operator's baseline performance from it's own memory. All devices share the information.
Frequency of calibration	Every time a new driver uses the vehicle, or every time power is switched off on the vehicle
Size cms	
Power requirements	12V D.C. from vehicle




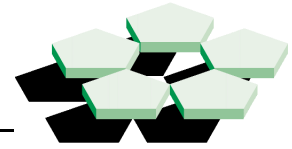
Company owning IPR	Australian Coal Association Research Programme (ACARP)
Name of device	Device for monitoring haul truck operator alertness
Cost per unit	\$9000 per vehicle on a yearly lease
Maintenance requirements	Has 1 year warranty, have had no failures in 8 months
Peripheral equipment required	Stimulus box is 70mm wide, 30mm high, 70mm deep. Reaction box is 130mm wide, 60 mm high and 230mm deep. One of each box is required.
Environment required for operation	Frequency for radio transmissions is 450Hz - 470Hz UHF using a 1 watt radio
Training required	Training to use the device as an operator takes around 30 minutes as the device is very simple to use. Training for the administrators of the system will take up to 60 minutes.
Availability	Not yet available as a commercial product
Has the device been approved?	The device is only a prototype
Has the device been proved of tried?	The device was being researched during 2000 and 2001
Which industries has it been used in?	Mining industry (vehicles)
Photographs	



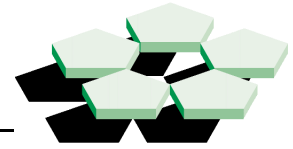
Company owning IPR	Applied Science Laboratories
Name of device	ETS-PC Eye tracking system
Patent number	Not known
Contact company or organisation	S Oliver Associates
Contact first name	Stephen
Contact surname	Oliver
Postal Address	Northumberland House, 11 The Pavement
Town or City	Popes Lane
County or State	London
Country	UK
Phone number	(0)20 8840 9910
Fax number	(0)20 8840 9915
Email	soliverassoc@compuserve.com
Web site	www.a-s-l.com
Source of information	Google, internet search, key word: eye tracking
Type of vigilance measured	Alertness/locus of attention
Physiological variable measured	Eye closure
Vigilance thresholds	Not known
Invasiveness	Non-invasive
Device response to reduced vigilance	Current device does not provide a response to reduced vigilance
Method of calibration	Typically calibration involves the subject looking at 9 points and takes approximately 20 seconds. However, automatic callibration can be incorporated.
Set up times	20 seconds
Set up requirements	The device requires calibration, to identify the typical position of the eyes and the range of eye movement. It is unclear how the equipment is set up before use, once fitted into a vehicle
Frequency of calibration	Once each time a driver enters a cab to start their shift.
Size cms	Not known
Power requirements	115/230v AC or 12v DC
Cost per unit	£1500 to £2000 for 100 000 units (for truck applications)
Mainenance requirements	Only general cleaning



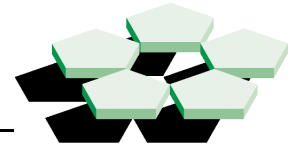
Company owning IPR	Applied Science Laboratories
Name of device	ETS-PC Eye tracking system
Peripheral equipment required	An eye camera module, 2 infra-red sources, imaging interfacing unit, system control unit, display unit, power transformer, lap top, and scene camera
Environment required for operation	The device is able to cope with conditions ranging from bright sunlight to darkness
Training required	Not known
Availability	Available as a commercial product
Has the device been approved?	No
Has the device been proved of tried?	The device is currently being used for research by a number of automobile manufactures including BMW, Mercedes Benz, Ford, Honda, Peugeot, Renault, and GM.
Which industries has it been used in?	Road transport
Photographs	 A photograph showing a person from the back seat of a car, looking at the driver. The driver is wearing a light-colored shirt and is holding the steering wheel. The car's interior, including the dashboard and rearview mirror, is visible.



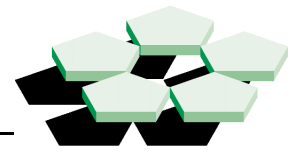
Company owning IPR	Seeing Machines
Name of device	faceLAB™ 2.0
Patent number	Not known
Contact company or organisation	Seeing Machines
Contact first name	Gavin
Contact surname	Longhurst
Postal Address	Innovations Building
Town or City	Corner Garran and Eggleston Rd
County or State	Canberra
Country	Australia
Phone number	+ [61] 2 6125 6501
Fax number	+ [61] 2 6125 6504
Email	info@seeingmachines.com
Web site	
Source of information	Google, internet search, key word: eye tracking
Type of vigilance measured	Alertness/drowsiness
Physiological variable measured	Eye blinks, eye closure
Vigilance thresholds	Uses PERCLOS fatigue assessment scale
Invasiveness	Non-invasive
Device response to reduced vigilance	Currently the device does not provide a response to a state of reduced vigilance.
Method of calibration	Not known
Set up times	Not known
Set up requirements	Not known
Frequency of calibration	Not known
Size cms	
Power requirements	
Cost per unit	
Mainenance requirements	

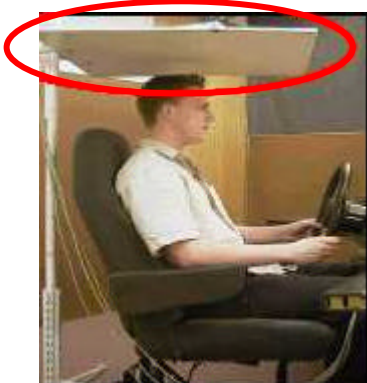


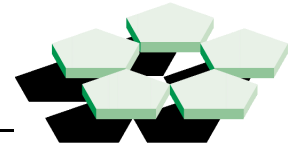
Company owning IPR	Seeing Machines
Name of device	faceLAB™ 2.0
Peripheral equipment required	Requires a stereo camera head, i.e. 2 cameras.
Environment required for operation	The eye closure fatigue measurements can only be taken when the eyes are visible. This may be affected with the use of sunglasses. The device can be used in the day time and night time
Training required	
Availability	Commercially available product
Has the device been approved?	No
Has the device been proved of tried?	Currently used as a research tool
Which industries has it been used in?	



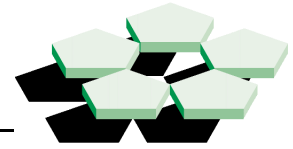
Company owning IPR	Advanced Safety Concepts, Inc (ASCI)
Name of device	MicroNod Detection System (MINDStm)
Patent number	US Patent No. 5 691 693, counterparts issues in Japan and EPO.
Contact company or organisation	Advanced Safety Concepts, Inc
Contact first name	Phil
Contact surname	Kithil
Postal Address	1570 Pacheco St. #E12
Town or City	Santa Fe
County or State	
Country	USA
Phone number	505-984-0273
Fax number	505-984-3269
Email	pkithil@headtrak.com
Web site	www.headtrak.com
Source of information	Internet search
Type of vigilance measured	Drowsiness
Physiological variable measured	Head movement
Vigilance thresholds	Three standard deviations of head movement behaviour above normal, alert 'baseline' head movement behaviour.
Invasiveness	Non-invasive
Device response to reduced vigilance	Visual notification is initiated when the ASCI system output is above its threshold for a specified percentage of time. If this percentage increases, visual notification is combined with a few-second audible notification. If the percentage of time above threshold continues to increase, the audible notification cycle time lengthens and repeats. A reset switch is provided to momentarily disable the notification devices.
Method of calibration	The device learns the typical head movements and behavioural patterns of the driver.
Set up times	Not known
Set up requirements	After system is installed, there are 3 potentiometers that require adjusting to predetermined values. An initial power-on with the seat unoccupied is required to bench mark the capacitive fields. The device learns the specific operator's alert patterns of head motion during an initial 15-20 minute training period.
Frequency of calibration	Currently, each time a vehicle is entered.
Size cms	See Equipment Required



Company owning IPR	Advanced Safety Concepts, Inc (ASCI)
Name of device	MicroNod Detection System (MINDStm)
Power requirements	12v at 0.5 amps
Cost per unit	Not known
Mainenance requirements	Not known
Peripheral equipment required	Three capacitive sensors contained in a foam -core module (2.5cm x 37.5cm x 45cm). This is connected to an electronics module (2.5cm x 10cm x 15cm) which holds the LEDs.
Environment required for operation	0 to 85 degrees C. The range of the sensor is 2.5cm min and 45 cm from the centre of the sensor. Need to be sure it is accurate in large vibration environments
Training required	Not known
Availability	Currently being developed
Has the device been approved?	No
Has the device been proved of tried?	Only through lab based reseach
Which industries has it been used in?	
Photographs	



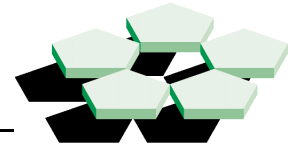
Company owning IPR	MTI Research Corp.
Name of device	Alertness Monitor ambulatory eye blink monitor
Patent number	
Contact company or organisation	MTI Research Corp.
Contact first name	Ed
Contact surname	MacLeod
Postal Address	7 Littleton Road
Town or City	Westford
County or State	
Country	USA
Phone number	(978) 692-9898
Fax number	(978) 692-9797
Email	conac@mtir.com
Web site	www.mtir.com
Source of information	from National Highway Transport Safety Association, USA. In an email from Ed McLeod, he stated that the device had been taken off the market.
Type of vigilance measured	
Physiological variable measured	
Vigilance thresholds	
Invasiveness	
Device response to reduced vigilance	
Method of calibration	
Set up times	
Set up requirements	
Frequency of calibration	
Size cms	
Power requirements	
Cost per unit	



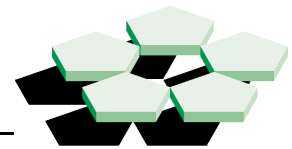
Company owning IPR	MTI Research Corp.
Name of device	Alertness Monitor ambulatory eye blink monitor
Maintenance requirements	
Peripheral equipment required	
Environment required for operation	
Training required	
Availability	
Has the device been approved?	
Has the device been proved of tried?	
Which industries has it been used in?	



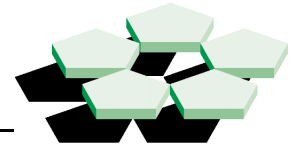
Company owning IPR	BRTRC Technology Research Corporation
Name of device	Vehicle Driver's Anti-Dozing Aid (VDADA)
Patent number	
Contact company or organisation	BRTRC Technology Research Corporation
Contact first name	Roger
Contact surname	Rogowski
Postal Address	8260 Willow Oaks Corporate Drive
Town or City	Suite #800
County or State	Fairfax
Country	USA
Phone number	(703) 204-9277
Fax number	(703) 204-9447
Email	rogowski@brtrc.com
Web site	www.brtrc.com
Source of information	From Report: 'REVIEW OF FATIGUE DETECTION AND PREDICTION TECHNOLOGIES', Institute for Research in Safety & Transport Murdoch University Western Australia. Rogowski, R., Rittenhouse, W., & Remson, A. (1997). Final Report: Vehicle Driver's Anti-Dozing Aid (VDADA). Technical Report prepared for the U.S. Army Tank Automotive and Armaments Command, Contract: DAAE07-96-c-X122 (September 1997). Fairfax, VA: BRTRC Technology Research Corporation.
Type of vigilance measured	Drowsiness
Physiological variable measured	Head movements, eye closure
Vigilance thresholds	Not known
Invasiveness	Headband mounted
Device response to reduced vigilance	There are three methods of alert. One is a vibrator with a beeper, mounted on the headband. The third is a carbon dioxide random burst to the temple area.
Method of calibration	Not known
Set up times	Not known
Set up requirements	Not known
Frequency of calibration	Not known
Size cms	Not known




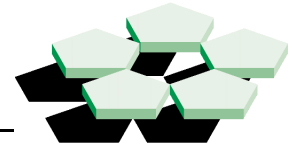
Company owning IPR	BRTRC Technology Research Corporation
Name of device	Vehicle Driver's Anti-Dozing Aid (VDADA)
Power requirements	Not known
Cost per unit	Not known
Maintenance requirements	Not known
Peripheral equipment required	Not known
Environment required for operation	Not known
Training required	Not known
Availability	The device was developed as part of a USA military research project. Mr. Rogowski was not contactable, so no further information was identified.
Has the device been approved?	Not known
Has the device been proved of tried?	Only in a research context
Which industries has it been used in?	



Company owning IPR	Driving Research Center,
Name of device	Copilot PERCLOS Monitor
Patent number	US Patent 1 6,082,858 - Apparatus and method of monitoring a subject's eyes using two different wavelengths of light
Contact company or organisation	Attention Technologies Inc.
Contact first name	Richard
Contact surname	Grace
Postal Address	10 40th Street
Town or City	Pittsburgh
County or State	
Country	USA
Phone number	412-681-6961
Fax number	412-681-6961
Email	rgrace@rec.ri.cmu.edu
Web site	www.cmu.edu/cmri/drc
Source of information	NHSTA report 'Biobehavioral Responses to Drowsy Driving Alarms and Alerting Stimuli' DOT HS 809 202.
Type of vigilance measured	Alertness/drowsiness
Physiological variable measured	PERCLOS (percentage eye closure)
Vigilance thresholds	First alert is when the PERCLOS level (P3) reaches 0.08. This is when the eyes are closed eight percent of the time over 60s (equivalent to 5s). Each subsequent alarm (6 in total) corresponds to an increase of P3 = 0.02
Invasiveness	Non-invasive
Device response to reduced vigilance	Visual and auditory warnings are provided. The visual warning employs 6 LED's, 3 amber and 3 red. The first amber LED corresponds to a PERCLOS level of P = 0.08. Each additional LED corresponds to an increase of 0.02. An audible warning of 3000Hz is presented on the first amber and the first red LED.
Method of calibration	The manufacturer states that no callibration is required
Set up times	Minimal
Set up requirements	The unit is mounted in front of the user. The unit has to be adjusted by the user such that they can see their reflection in the face of the unit.
Frequency of calibration	Callibration not required
Size cms	See below

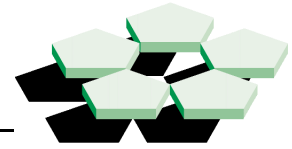


Company owning IPR	Driving Research Center,
Name of device	Copilot PERCLOS Monitor
Power requirements	The device is powered by 123v and draws 600mA
Cost per unit	\$5000 for an evaluation unit, \$800 for a production model
Mainenance requirements	Maintenance issues, failure rates and reliability data is not known at this time.
Peripheral equipment required	A main unit that contains the sensor equipment and display, and a base unit upon which the main unit sits. The main unit is 280g, 13x7x15cm, the base unit is 3cm tall
Environment required for operation	The device only works at night. Furthermore, the device works when the driver is wearing corrective spectacles or contact lenses, but not sunglasses. The device works up to 2m away from the driver, but the distance could be improved with different lenses.
Training required	Adjusting the device and responding to the alarm
Availability	Currently an evaluation unit, used for laboratory experments
Has the device been approved?	The production device will include ISO and SAE standards for automotive electronics
Has the device been proved of tried?	The Copilot is an evaluation unit. It will be in full production in late 2003.
Which industries has it been used in?	Intended for road transport
Photographs	

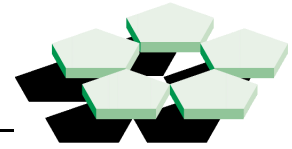


Appendix B: Physiological measures database

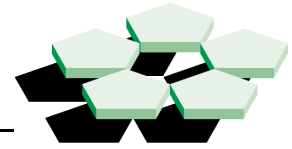
Name of index	Electroencephalography (EEG)
Description of index	EEG is the measurement of brain electrical activity (central nervous system function) over time.
How does the index measure the alertness/drowsiness/readiness?	EEG is described using frequency ranges known to be related to sleepiness and alertness namely delta (0.5-3 Hz), theta (3 - 7.5hz) alpha (7.5 - 13 Hz) beta 1(13-20 Hz), beta 2 (20-30 Hz). Alert wakefulness is characterised by predominantly alpha and beta EEG activity frequencies. Sleepiness is characterised by increased rhythmic EEG alpha activity. Drowsy sleep is characterised by the presence of theta EEG activity frequencies. Sleep is characterised by continuous relatively high amplitude theta or delta activity.
How is the index correlated to performance?	Reference 2 studied operators who were engaged in a simulated passive sonar auditory detection task. They examined the EEG spectra surrounding 'lapses' (targets eliciting no response) and 'hits' (targets eliciting responses) during drowsy periods. Immediately before lapses, power (mean square amplitude) between 2-5 Hz increased and power near 40 Hz decreased (40 Hz EEG power increases with alertness).
How are measurements taken?	Measurements are taken from the scalp overlying the occipital and parietal regions of the brain. Electrodes are positioned at specific locations on the scalp. The number and position of electrodes varies.
What are the measures thresholds?	It is thought that theta EEG activity can be used to predict performance lapses and drowsiness. Some devices record EEG activity of a user and compare it to a database of EEG recordings ranging from fully alert to asleep. The EEG states held in the database are used to predict the users current state.
Problems with this index	Recordings of EEG can be sensitive to artifacts such as muscle and eye movement. These have to be accounted for and removed to ensure reliability and accuracy. Optimum electrode positions have to be defined and must have good contact with the scalp. Furthermore, Reference 2 has identified large individual differences in EEG recordings across subjects, which would need to be accounted for in any device.
References for information	1. Belyavin and Wright 1987, Changes in electrical activity of the brain with vigilance, <i>Electroencephalography and Clinical Neurophysiology</i> , 66, 137 - 144 2. Makeig, S., Jung, Tzyy -Ping, Sejnowski, T.J., Stensmo, T.J., 1997, Estimating alertness from the EEG power spectrum, 1997, <i>IEEE transactions on biomedical engineering</i> , vol 44, no. 1.



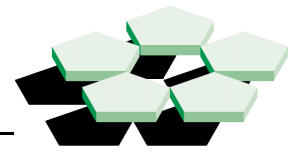
Name of index	Eye blink activity (blink duration, blink amplitude and blink rate)
Description of index	Stern et al (reference 2) reported that blink rate (number of blinks per second) and duration (duration of eye closure) typically increase with time on task and fatigue.
How does the index measure the alertness/drowsiness/readiness?	Blink occurrences can be defined as a percentage of eye closure or complete closure relative to the average pupil size. Blink duration can be defined as the time interval between blink onset and the return of pupil diameter to a percentage of eye closure. Blink rate can be defined as the number of blink occurrences per unit time. An average, typical blink rate is measured for an individual whilst they are alert (i.e. with no sleep deprivation effects). Eye blink rate and duration is then measured and compared to the baseline blink rate and duration.
How is the index correlated to performance?	Reference 3 performed an experiment to compare different types of eye activity against performance during a tracking task. The experiment was conducted over a 2 hour period, with subjects that were not sleep deprived. The data generally supports the theory that eye blink activity covaries with changes in performance due to drowsiness and loss of vigilance.
How are measurements taken?	Measurements of blink rate can be performed using eye-tracking cameras (either video or infra-red) mounted in front of the user or on the user (head set), or using EOG techniques. 2 - 6 electrodes are placed on the head to detect the signals generated by the motor units involved in contraction of the muscles of the eye
What are the measures thresholds?	Generally, the literature suggests that blink duration and frequency is correlated with a reduction in performance due to fatigue. However, thresholds for drowsiness and reduced vigilance are not provided.
Problems with this index	The application of this index depends on how blink activity is measured and how blinks occurrences are defined. 'Blink standards' for determining a blink are required. For example a blink can be defined as the duration of eyelid closure or the amount of pupil occlusion. This needs to take into account variations in pupil size and eyeball size. Blink rate may be affected by environmental factors such as humidity or air velocity, and by personal factors such as allergies. The definition of blinks can change according to pupil size.
References for information	1. Dinges, D.F., Mallis, M.M., Maislin, G., and Walker Powell IV, J. 1998 'Evaluation of techniques for ocular measurement as an index of fatigue and as the basis for alertness management', National Highway Traffic Safety Administration, DOT HS 808 762, Springfield, VA, 2. Stern, J.A., Boyer, D., Schroeder, D. 1994. 'Blink rate: a possible measure of fatigue', Human Factors, 36, 285-297. 3. Orden, K.F., Jung, Tzyy -Ping, Makeig, S., 2000 'Combined eye activity measures accurately estimate changes in sustained visual task performance', Biological Psychology, 52, 221 - 240, Elsevier.



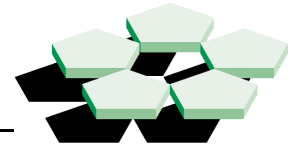
Name of index	Eye movements
Description of index	Eye movements include saccade (eye movement associated with fixation gazes) frequency, fixation duration, saccade duration, saccade amplitudes, and velocity of saccades. These alter with time on task and low levels of arousal.
How does the index measure the alertness/drowsiness/readiness?	Saccade frequency is the frequency with which the eye moves. Saccade amplitude is the size of the eye movement from a neutral position. These are usually measured over a period of time. Eye movements are typically monitored for an individual whilst they are alert, possibly whilst performing a task. Eye movement is then measured and compared to the baseline movements.
How is the index correlated to performance?	The frequency of large amplitude eye movements has been shown to decrease with time-on-task in automobile drivers (Reference 1). Rate of change of amplitude is a good indicator of sleep, and of drowsiness states (Reference 2). Saccade duration increases with time on task, which could be related to fatigue (Reference 3).
How are measurements taken?	Measurements of blink rate can be performed using eye-tracking cameras (either video or infra-red) mounted in front of the user or on the user (head set), or using EOG techniques. 2 - 6 electrodes are placed on the head to detect the signals generated by the motor units involved in contraction of the muscles of the eye
What are the measures thresholds?	Measurements of EOG correlate to EEG measures of vigilance, showing distinct patterns of rate of change of movement for different stages of arousal.
Problems with this index	Eye movements could be considered an indicator of fatigue, but can be affected by the nature of a task. For example, when performing a visual task on a screen, eye movement amplitude can vary with distance away from screen. Furthermore, blink closures and durations are claimed to be more sensitive measures of fatigue and time on task effects than eye movement (Reference 3).
References for information	1. Ceder, A., Driver's eye movements as related to attention in simulated traffic flow conditions, Human Factors, 1977, 19, 571-581. 2. Wright, N. and McGown, A., Vigilance on the civil flight deck: incidence of sleepiness and sleep during long-haul flights and associated changes in physiological parameters 3. McGregor, D. K. and Stern, J. A., 1996, Time on task and blink effects on saccade duration, Ergonomics, 39, 4, 649-660.



Name of index	PERCLOS
Description of index	PERCLOS is based on studies of drivers in car simulators who exhibit distinct facial and eye changes when fatigued. Drowsy drivers were reported to have decreased facial muscle tone, slow eye movements and long eyelid closure compared to alert drivers.
How does the index measure the alertness/drowsiness/readiness?	PERCLOS is a measure of proportion of time that the eyeslids of a subject are partially closed, as judged by an observer or a dedicated software application. The drowsiness criterion is the proportion of time the eyes are judged to be >80% closed during 1 minute. Drowsy subjects are reported to have decreased facial tone, slower eyelid movements and longer eyelid closure (2+ sec).
How is the index correlated to performance?	Reference 1 (below) describes an experiment performed for the US National Highway Traffic Safety Administration which demonstrates that PERCLOS measures of alertness/drowsiness correlate highly in lapses in performance during psychomotor vigilance tasks (PVT). It performed well within subjects (over a number of test bouts) and across subjects and predicted lapses during the first 22 hr period of the experiment.
How are measurements taken?	The process of recording eye closure has been automated using eye tracking digital cameras and specially design software.
What are the measures thresholds?	The threshold for determining drowsiness is the proportion of time the eyes are judged to be >80% closed during 1 minute. If this threshold is exceeded then a person is claimed to be drowsy
Problems with this index	The PERCLOS index has been proved in the laboratory to be an excellent measure of fatigue and drowsiness. However, the index may only be useful for predicting the immediate onset of sleep incidents. There are also the issues of human variability in pupil size, eye blink behaviour, effects of the environment and personal factors to be considered.
References for information	1. David F. Dinges, Ph.D., Malissa M. Mallis, Greg Maislin, MA, MS., John Walker Powell, IV, M.A. Final Report: Evaluation of Techniques for Ocular Measurement as an Index of Fatigue and as the Basis of Alertness Management, US National Highway Traffic Safety Administration, Report no DOT HS 808 762, April 1998.



Name of index	Electrodermal activity (EDA)
Description of index	EDA is the electrical activity, resistance and potential, at the skin surface. The level of activity reflects certain mental states.
How does the index measure the alertness/drowsiness/readiness?	It has been shown that electrical resistance of the skin is not a constant value, and is liable to two types of changes: 1. Slow variations of electrodermal resistance, which change over a period of minutes and hours. These relate to the nervous stimulation to muscles. 2. Fast changes of several hundred Ohm or kOhm as a response to sensory or emotional stimulation. This Electrodermal Reaction is a derivative of the electrodermal resistance, and has been shown to be sensitive to reductions in alertness, and possibly lapses in concentration.
How is the index correlated to performance?	A relationship between electrodermal activity and arousal has been established in Reference 1 and 2. Reference 2 showed that the electrodermal activity (skin potential) reduced in negativity according to a decrease in task performance. Reference 3 showed that the frequency of electrodermal responses decreased preceding a task error. Furthermore, the decrease in EDR was correlated with reaction times during a visual recognition test.
How are measurements taken?	EDA is measured using electrodes attached to the skin. These measure the electrical activity at the skin's surface over time. The measures are generally amplified by a preamp and then recorded on a polygraph.
What are the measures thresholds?	EDA is useful as a measure of the level of arousal when subjects feel drowsy but not on the brink of falling asleep. Reference 2 and 3 show that EDA is a reliable measure of task error before EEG measures show the presence of sleep indicators (e.g. rhythmic alpha activity and theta activity).
Problems with this index	Electrodermal responses to emotional and sensory stimulation are affected by muscle electrical activity and spontaneous electrical responses. These artifacts have to be removed to discriminate arousal related responses.
References for information	1. Mental activity and electrodermal phenomena, in J.L. Andreassi (ed.), Psychophysiology: Human Behaviour and Physiological Response, 3rd edn (Hillsdale p175-180). 2. Nishimura, C., and Nagumo, Jin-Ichi, 'Feedback control of the level of arousal using skin potential level as an index' 1985, Ergonomics, 28, 6, 905-913. 3. Dorokhov, V.B., Dementienko, V.V., Koreneva, L.G., Markov, A.G., Shakhnarovitch, V.M., Zakharov, P.V., 1998, International Journal of Psychophysiology, 30, 1-2, p267.



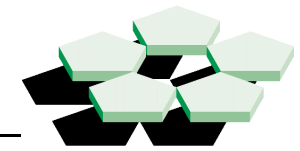
Name of index	Heart measures
Description of index	Heart measures include heart rate, which is the number of heart beats per unit time, time between successive beats, peak frequencies in EKG patterns, and peak frequency components.
How does the index measure the alertness/drowsiness/readiness?	Heart rate and peak frequency components have been used to as an indicator of the variable in experiments.
How is the index correlated to performance?	Studies have shown that a certain component of peak frequency is correlated with fatigue in a driving task (Reference 1). In a lab based monotonous task (Reference 2), the central-nervous arousal found in the EEG corresponded to distinct increases in heart rate. This was not, however, correlated to task performance. Reference 3 showed that heart rate correlated with brainwave activity to indicate drowsiness during a study on pilots. Heart measures may be a better indicator of arousal, rather than a direct measure of task performance.
How are measurements taken?	Electrodes are placed on the surface of the chest which detect the patterns of a beating heart. The device used for measuring heart beat patterns is an electrocardiogram (EKG).
What are the measures thresholds?	It is the case that average heart rate decreases with increases in 'drowsy state' EEG patterns, and increases with 'alert' EEG patterns. The thresholds are not clear from research carried out using heart measures.
Problems with this index	It is not clear how sensitive heart rate is, and how quickly it changes with arousal. Heart rate can be affected by many psychological processes, such as fear or anxiety, that it may not be a reliable measure for practical purposes.
References for information	1. Egelund, N. Spectral analysis of heart rate variability as an indicator of driver fatigue, <i>Ergonomics</i> , 1982, 25, 663-672. 2. Occupational Performance of a Paced Secondary Task under Conditions of Sensory Deprivation. I. Heart Rate Changes in Train Drivers as a Result of Monotony, Peter, J.H., Cassel, W. Ehrig, B.; Faust, M.; Fuchs, E.; Langanke, P.; Meinzer, K.; Pfaff, U, <i>European Journal of Applied Physiology and Occupational Physiology</i> , 1990, 60, 4, 309-314



Name of index	Reaction time to a stimulus
Description of index	A subject is presented with a secondary decision reaction time task to perform, in addition to their primary task (e.g. driving a train or motor vehicle). The reaction time is measured, and compared to an average time.
How does the index measure the alertness/drowsiness/readiness?	Reaction time decision tasks have both decision making cognitive components and psychomotor (muscle movement and control) components. Cognitive function reduces with fatigue. A subject finds it more difficult to perform mental tasks such as mental arithmetic, memorising objects or characters, or making decisions. The index incorporates a decision component (e.g. presenting a choice of stimulus to which a response is required) to test the effects of fatigue on cognitive function, and therefore the subject's vigilance.
How is the index correlated to performance?	The application of this technique has been reported in Reference 1. The device was trialed over 18 months in the four situations, enabling sufficient data to assess the practical utility of the device and to a lesser extent, the scientific validity of the monitor. The device shows high validity at detecting alert and very tired episodes, as shown by the eye measure taken within the trials.
How are measurements taken?	Measurements are taken from a device that presents a choice of stimuli (visual or auditory) to the subject, which they must respond to correctly and within the time limits by selecting corresponding buttons.
What are the measures thresholds?	The threshold given in Reference 1 is a reaction time that is 2 standard deviations or more about the subjects average, 'alert' reaction time.
Problems with this index	Reaction time tests introduce a task to the working environment that may distract the subject from their primary task.
References for information	1. Mabbott, N., Procedures and Devices to Monitor Operator Alertness Whilst Operating Machinery in Open Cut Coal Mines - Stage 3: Trial of the Fatigue Monitor, 2002, Contract report for Australian Coal Association Research Program - Contract C9032.

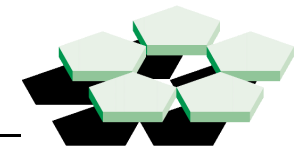


Name of index	Head movement
Description of index	Head movement or head position at the neck relative to a neutral posture, and relative to the rest of the body is believed to change with alertness and fatigue.
How does the index measure the alertness/drowsiness/readiness?	With increasing fatigue muscle tension in a persons neck may begin to reduce, causing the head to bob, droop or roll. These actions are measured over time to provide an indication of the level of drowsiness.
How is the index correlated to performance?	There does not appear to be much reasearch that uses head movement to indicate performance lapses. Reference 1, a comparison of 6 drowsiness monitoring technologies (including a head movement technology) in a driving simulator found that only eye closure consistently predicted lapses in performance. This appears to agree with the findings of Reference 2.
How are measurements taken?	Muscular activity can be measured with surface electrodes placed near or over the muscle. A device is now available that is designed to record the x,y, and z coordinates of the head using magnetic fields
What are the measures thresholds?	The company MINDs have characterised 5 types of head movement and head motions that indicate a level of alertness. These have been expressed mathematically and are used to determine alertness based on head movement information provided by the sensors. This method is specific to MINDs' device, but may still be appropriate for other head movement measures.
Problems with this index	In an experiment comparing alertness monitoring technologies (reference 2), a head position sensor recorded head nod events before recorded microsleeep periods, but also showed that mircrosleeps occurred without head nods. This suggests that head movement alone may not be a good indicator of drowsiness.
References for information	1. David F. Dinges, Ph.D., Malissa M. Mallis, Greg Maislin, MA, MS., John Walker Powell, IV, M.A. Final Report: Evaluation of Techniques for Ocular Measurement as an Index of Fatigue and as the Basis of Alertness Management, US National Highway Traffic Safety Administration, Report no DOT HS 808 762, April 1998. 2. Anneke Heitmann, A., Rainer Guttkuhn, R., Acacia Aguirre, A., Udo Trutschel, U. and Martin Moore-Ede, E., Technologies for the monitorin and prevention of driver fatigue, Proceedings of the First International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design

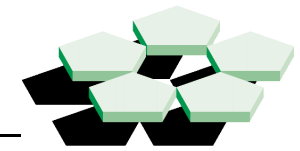


Appendix C: Device evaluation against User Acceptance Criteria

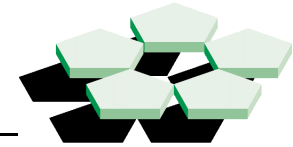
		Eye Tracking Alertness monitor	ABM Drowsiness Monitoring Device (DMD)	Photo Driven Alert System (Patent 0208247.7)	Engine Driver Vigilance Telemetric Control System (EDVTCS), 3rd Generation	Hypovigilance Diagnosis Module (HDM) and Driver Warning System
No	Criteria	Future of Technology and Health	Advanced Brain Monitoring Inc	Michael Myronko	J-S Co. NEUROCOM	Part of the EU's Information Society Technologies (IST) research programme
UA1.	The device must not distract the driver from their primary task or responding to other safety devices (e.g. AWS, TPWS)	The device may false alarm if a driver is looking down at their lap	Criteria met pending full scientific testing and trial	Criteria met pending full scientific testing and trial	Criteria met pending full scientific testing and trial	
UA2.	The device must not be invasive	Criteria met - Not invasive	Criteria not met. Device uses conductive gel to improve the contact between the user and the sensors	Criteria met	Criteria met	
UA3.	Wearable devices must accommodate the variations in driver anthropometric dimensions	Not applicable	Criteria met. Device headset is available in four different sizes.	The adjustability of the device has yet to be assessed for this project	Criteria met	
UA4.	Devices that take measurements remotely must accommodate variations in sitting height	Would be an issue if the layout and design of the train cab was such that the options for locating the device is restricted	Not applicable	Not applicable	Not applicable	
UA5.	Devices must accommodate variations in driving posture and driver behaviours whilst driving	Accommodates head movement of 30cm in any direction. This may not be adequate for train driving activities	Criteria met. Head set has to be within 20ft of the processor/analyser	Criteria met. Device is worn over the ear.	Criteria met. Device range is 2m from the receiver.	
UA6.	The device shall accommodate physiology and behavioural changes in the driver that result from the state of the cab's thermal and illumination environment	The device may alarm in the event of the driver squinting due to bright sunlight	Criteria met	The device may alarm in the event of the driver squinting due to bright sunlight	Criteria met. Device electrodes are not affected by sweating.	
UA7.	Devices must accommodate religious head-dresses worn by Sikhs, and the wearing of hard-hats	Not applicable	Criteria not met. Device has to be worn on the head of the driver	Criteria met	Criteria met	
UA8.	Devices must accommodate corrective spectacles and sunglasses	Criteria not met. Device does not accommodate sun glasses	Not applicable	Criteria not met. Device worn on ear so is difficult to wear spectacles comfortably	Not applicable	
UA9.	Calibration of the device should only be required once during a driver's shift	Criteria met. Device calibrates automatically when started up. Recalibration required for a new driver	Criteria met. The device requires a one-time calibration for new drivers	Criteria met. Calibration not required	Criteria met	
UA10.	Calibration to the driver's physiological state should not take longer than 5 minutes	Criteria met. Set up estimated at a few minutes	Criteria met. Cap application is 3-5 minutes	Criteria met	Criteria met. Calibration takes 10-20s	
UA11.	If the device requires up-to-date data on the driver's physiology, then it should be done every 5 years	Criteria met.	The effect of change in physiology on EEG activity is yet to be identified for this project.	Not applicable	Not applicable	
UA12.	The device should present an auditory alert to the driver in the cab	Criteria met	Criteria met.	Criteria met	Criteria met	
UA13.	The alert should be distinct from other in-cab safety alerts	Compliance with noise standard GM/RT2161 to be performed for final report	Compliance with noise standard GM/RT2161 to be performed for final report	Compliance with noise standard GM/RT2161 to be performed for final report	Compliance with noise standard GM/RT2161 to be performed for final report	
UA14.	The alert should not be masked by other alerts, horns or ambient cab noise	Compliance with noise standard GM/RT2161 to be performed for final report	Compliance with noise standard GM/RT2161 to be performed for final report	Compliance with noise standard GM/RT2161 to be performed for final report	Compliance with noise standard GM/RT2161 to be performed for final report	
UA15.	The device shall have a control to cancel/acknowledge an alert	Criteria met. Alarm is cancelled when eyes are fully open or when a time period passes.	Not known at time of writing	Criteria met. Control provided	Criteria met. Control provided	



		Device for monitoring haul truck operator alertness	ETS-PC Eye tracking system	faceLAB™ 2.0	MicroNod Detection System (MINDStm)	Vehicle Driver's Anti-Dozing Aid (VDADA)	Copilot PERCLOS Monitor
No.	Criteria	Australian Coal Association Research Programme (ACARP)	Applied Science Laboratories	Seeing Machines	Advanced Safety Concepts, Inc (ASCI)	BRTRC Technology Research Corporation	Driving Research Center
UA1.	The device must not distract the driver from their primary task or responding to other safety devices (e.g. AWS, TPWS)	Criteria not met. Device requires a secondary task	Criteria met pending full scientific testing and trial	Criteria met pending full scientific testing and trial	Criteria met pending full scientific testing and trial	Criteria met pending full scientific testing and trial	Criteria met pending full scientific testing and trial
UA2.	The device must not be invasive	Criteria met	Criteria met	Criteria met	Criteria met	Criteria met	Criteria met
UA3.	Wearable devices must accommodate the variations in driver anthropometric dimensions	Not applicable	Not applicable	Not applicable	Not applicable	Not known at time of writing	Not applicable
UA4.	Devices that take measurements remotely must accommodate variations in sitting height	Not applicable	Would be an issue if the layout and design of the train cab was such that the options for locating the device is restricted	Would be an issue if the layout and design of the train cab was such that the options for locating the device is restricted	The sensor range is 45cm from the centre of the sensor. If the device is mounted on a cab ceiling it may not pick up driver movements	Not applicable	Would be an issue if the layout and design of the train cab was such that the options for locating the device is restricted. Device works up to 2m away from the driver
UA5.	Devices must accommodate variations in driving posture and driver behaviours whilst driving	The location of the device in the train cab would have to take these issues into consideration	Criteria met.	Not known at the time of writing	Not known at the time of writing	Not known at the time of writing	Not known at time of writing
UA6.	The device shall accommodate physiology and behavioural changes in the driver that result from the state of the cab's thermal and illumination environment	Criteria met	The device may alarm in the event of the driver squinting due to bright sunlight	Not known at the time of writing	Criteria met	Criteria met	Criteria met
UA7.	Devices must accommodate religious head-dresses worn by Sikhs, and the wearing of hard-hats	Criteria met	Criteria met	Criteria met	The effect of wearing head dresses and hard-hats on head movement measurement is not known at the time of writing	Criteria not met. Device is mounted on a band which is worn on the head.	Criteria met
UA8.	Devices must accommodate corrective spectacles and sunglasses	Not applicable	92% corrective spectacles and lenses. Good quality sunglasses, cheap ones reflect IR	Not known at the time of writing	Criteria met	Criteria met	Criteria not met. Device only works at night
UA9.	Calibration of the device should only be required once during a driver's shift	Criteria met	Criteria met.	Not known at the time of writing	Criteria met.	Not known at time of writing	Criteria met. No calibration required
UA10.	Calibration to the driver's physiological state should not take longer than 5 minutes	Criteria met.	Criteria met. Calibration takes approx. 20s	Not known at the time of writing	Criteria met. Calibration is performed without driver intervention	Not known at time of writing	Criteria met
UA11.	If the device requires up-to-date data on the driver's physiology, then it should be done every 5 years	The device required specific baseline data on the driver. The frequency of up-dating data baselines requires investigating	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
UA12.	The device should present an auditory alert to the driver in the cab	Criteria met	Criteria not met. Device currently does not provide an alert	Criteria not met. Device currently does not provide an alert	Criteria met	Criteria met	Criteria met
UA13.	The alert should be distinct from other in-cab safety alerts	Compliance with noise standard GM/RT2161 to be performed for final report	Not applicable	Not applicable	Compliance with noise standard GM/RT2161 to be performed for final report	Compliance with noise standard GM/RT2161 to be performed for final report	Compliance with noise standard GM/RT2161 to be performed for final report
UA14.	The alert should not be masked by other alerts, horns or ambient	Compliance with noise standard GM/RT2161 to be performed for final	Not applicable	Not applicable	Compliance with noise standard GM/RT2161 to be performed for	Compliance with noise standard GM/RT2161 to be performed for final	Compliance with noise standard GM/RT2161 to be performed for



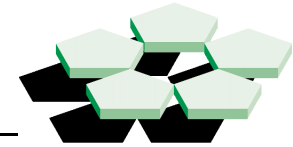
		Device for monitoring haul truck operator alertness	ETS-PC Eye tracking system	faceLAB™ 2.0	MicroNod Detection System (MINDStm)	Vehicle Driver's Anti-Dozing Aid (VDADA)	Copilot PERCLOS Monitor
No.	Criteria	Australian Coal Association Research Programme (ACARP)	Applied Science Laboratories	Seeing Machines	Advanced Safety Concepts, Inc (ASCI)	BRTRC Technology Research Corporation	Driving Research Center
	cab noise	report			final report	report	final report
UA15.	The device shall have a control to cancel/acknowledge an alert	Criteria met	Not applicable	Not applicable	Criteria met. Control provided	Not known at time of writing	Not known at time of writing



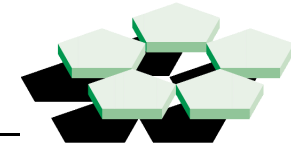
Appendix D: Device evaluation against UK Railway Context Criteria

		Engine Driver Vigilance Telemetric Control System (EDVTCS), 3rd Generation	MicroNod Detection System (MINDStm)
No.	Criteria	J-S Co. NEUROCOM	Advanced Safety Concepts, Inc (ASCI)
RC1.	The device shall have the facility of being connected to other train interface components (such as the traction brake controller and the AWS)	The device is current in use with the Russian Railways and is connected to other safety devices in the train	It is not clear whether the device has any outputs
RC2.	The device should have the facility to record and store physiological data	It is not clear from the device literature whether the device records and stores physiological data	It is not clear from the device literature whether the device records and stores physiological data
RC3.	The data recorded and stored on the device should be easy to retrieve and understand	See above.	See above
RC4.	The device shall have the facility to connect with the train's OTMR	To assess this criteria would require consultation with an OTMR expert	To assess this criteria would require consultation with an OTMR expert
RC5.	Eye tracking devices will have to be compatible with behaviours adopted by drivers in trains with in-cab signalling.	Not applicable	Not applicable
RC6.	If the device uses telemetry for transferring data, data transfer should not adversely affect current and future train-to-track wireless communications	The radio frequency of the device communication is 17000MHz. The power output of the radio signal is 6 mcW. This would have to comply with EMC requirements	Not applicable
RC7.	If the device uses telemetry for transferring data, data transfer should not be adversely affected by current and future train-to-track wireless communications	See above.	Not applicable
RC8.	The device should be robust against magnetic (or otherwise) interference from traction motors, overhead power cables and the electrified third rail	The device is currently in use with the Russian Railways so is likely to be robust against magnetic interference	The device may not be robust against magnetic interference as it relies on capacitance to obtain its readings
RC9.	The device shall be compliant with GMRT/2000	Device should be evaluated against GMRT/2000	Device should be evaluated against GMRT/2001

Appendix D.1

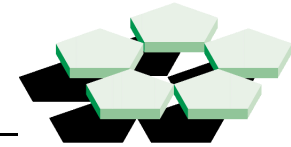


		Engine Driver Vigilance Telemetric Control System (EDVTCS), 3rd Generation	MicroNod Detection System (MINDStm)
No.	Criteria	J-S Co. NEUROCOM	Advanced Safety Concepts, Inc (ASCI)
RC10.	The device shall be able to operate in both air-conditioned and non-air conditioned environments	The device operates within the Russian Railway cab environmental conditions	The device operates in temperature conditions between 0 and 85 degrees C
RC11.	The device shall not add to the thermal load of the cab	Not known at the time of writing	Not known at the time of writing
RC12.	The device shall be able to operate in both day time and night time illumination conditions	It is not clear from the device literature whether the display has luminance controls	The device provides a visual notification in the event of a vigilance decrement, however it is not clear whether the display has luminance controls
RC13.	The device manufacturer shall be able to provide an operating manual	Criteria met	Not known at the time of writing
RC14.	Head movement tracking devices will have to be compatible with behaviours adopted by drivers in trains with in-cab signalling.	Not applicable	It should be determined how the device would cope with drivers alternating between viewing the in-cab signalling and the track

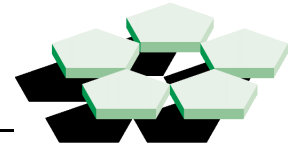


Appendix E: Device evaluation against Scientific Criteria

No	Criteria	Engine Driver Vigilance Telemetric Control System (EDVTCS), 3rd Generation, J-S Co. NEUROCOM
Internal validity		
General		
SC1.	What are the measures of task performance used to validate the device? Does the task and performance measure relate to the driving task?	The tests used to validate the device were laboratory based vigilance tasks (SC9), however the device is currently being used on the Russian railways.
SC2.	Does the device measure what it's supposed to operationally? What else could the test be measuring?	The device takes measurements of the electrical activity at the skin's surface over time via electrodes located in a wrist watch, and calculates the derivative of the electrodermal resistance in real time (this is called the Electrodermal Reaction). This is a typical method for measuring skin electrical activity. The device uses bespoke algorithms to remove artefacts such as electrical activity from muscle movements.
SC3.	Does the device measure what it's manufacturers claim, conceptually?	The device claims to measure vigilance, that is, a persons ability to respond in some way to the occurrences of relatively infrequent and unpredictable (in time, space, or both) stimulus changes over relatively long periods of time. The research literature provided by the device manufacturer has shown a significant link between electrodermal reactions (EDR) and reaction time. The ability to react to stimulus is related to vigilance.
SC4.	Does the physiological index that the device is measuring relate to the driver's performance?	Separate research was conducted using a visually monotonous task, and psychomotor vigilance task. Both experiments showed that reductions in EDR preceded task errors and increases in reaction time.
SC5.	How do the device measurement results relate to subjective measures?	Subjective measures have not been reported in the literature
SC6.	Use of parametric tests (high power).	The experiments referred to in SC4 used 11 and 64 participants respectively. The literature provided by the manufacturer states that 6500 test subjects have been used and 20 years of research have dedicated to proving the technology.
Criterion validity		
SC7.	Has the index been benchmarked against other, established indexes that measure the same variables?	The results of EDR measures has been compared to EEG measures in many of the experiments performed using the device, mainly to verify the EDR measures. It has been shown that the changes in the number of EDRs measured corresponds to wake-drowsy cycles give by EEG measures.
SC8.	Are the test predictions correct? e.g. are the results significant?	The research literature provided by the manufacturer suggests that the device has proven to be a predictor of reduced vigilance.

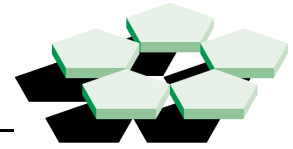


No	Criteria	Engine Driver Vigilance Telemetric Control System (EDVTCS), 3rd Generation, J-S Co. NEUROCOM
Reliability		
SC9.	Is the device consistent in its measurement over a number of treatments?	From the research literature two types of vigilance test were used during the validation experiments - a counting button press test, and a visual detection test. The results are consistent across tests.
SC10.	Have repeated measures been used?	It is not clear from the research documentation whether repeated measures were used.
Sensitivity		
SC11.	How many times will the device miss an event? (False-negative)	The literature states that the probability of the device not predicting a state preceding sleep is 0.00001.
Specificity		
SC12.	How many times will the device present a false alarm? (False-positive)	The false alarm probability is 0.08. The literature states that if the device detects a vigilance level lower than the acceptable threshold, 8 out of 100 times it will be incorrect.
Generalisability/ external validity		
Population validity		
SC13.	Does it measure the same events for all people?	The experiments conducted to validate the research has used subject aged 16-69, of both sexes. Experiments were conducted to determine individual differences in the wakefulness measures, the transition to drowsiness and also gender differences. The research suggests that there are no gender differences during wakeful periods and some differences during the transition to drowsiness. There are individual differences for transition to drowsiness. The tends for EDR response are the same.
SC14.	How did the results perform between subjects?	
SC15.	How did the results perform across subjects?	
SC16.	Does it take into consideration subject variability?	
SC17.	Does the population used for the test match train driver population characteristics?	The literature does not explicitly state the population type used for the validation experiments.
Ecological validity		
SC20.	What was the duration of the test?	The duration of the tests given in the research literature was around 30-40mins. This compare to around 6 - 8 hours for a driver's duty cycle. However, mean time between stops would be much shorter.

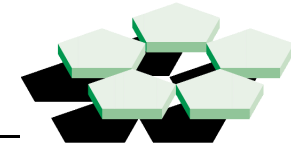


Appendix F: UK Rail Rolling Stock

Class	Introduced	Number in use	Type
8	1953	265	Diesel Electric
9	1959	36	Diesel Electric
20	1957	40	Diesel Electric
31	1957	138	Diesel Electric
33	1960	30	Diesel Electric
37	1960	289	Diesel Electric
43	1976	196	Diesel Electric
47	1963	331	Diesel Electric
56	1976	126	Diesel Electric
58	1983	50	Diesel Electric
59	1985	15	Diesel Electric
60	1989	100	unknown
66	on order	220	CoCo Locomotive
67	on order	30	CoCo Locomotive
73	1965	44	Diesel And Electric @ 750V DC 3rd Rail
86	1965	95	Electric @ 25kV AC 50hz
87	1973	36	Electric @ 25kV 50hz
89	1987	1	Electric @ 25kV 50hz
90	1987	50	Electric @ 25kV 50hz
91	1988	31	Electric @ 25kV 50hz
92	1994	37	Electric @ 750V DC & 25kV AC 50 Hz
101	1958	36	DMU 2
117	1959	17	DMU 3
121	1960	4	DMU 1
142	1984	9	DMU 2
142	1985	96	DMU 2
143	1985	25	DMU 2
144	1986	23	DMU 2
150	1986	131	DMU 2
153	1987	70	DMU 1
155	1988	7	DMU 2
156	1987	86	DMU 2
158	1990	182	DMU 2
159	1992	22	DMU 3
165	1990	76	DMU 2
166	1992	21	DMU 3
168	1998	5	DMU-4
170	on order	33	DMU-3
170	on order	40	DMU-2
205	1957	10	DEMU 3
207	1962	4	DEMU 2
302	1958	29	EMU 4
303	1959	46	EMU 3
305	1960	14	EMU 3
308	1961	21	EMU 3
309	1962	6	EMU 4
310	1965	48	EMU 3
312	1976	49	EMU 4
313	1976	64	EMU 3



Class	Introduced	Number in use	Type
314	1979	16	EMU 3
315	1980	59	EMU 4
317	1981	79	EMU 4
318	1985	21	EMU 3
319	1987	86	EMU 4
320	1990	22	EMU 3
321	1988	117	EMU 4
322	1990	5	EMU 4
323	1992	43	EMU 3
332	1997	14	EMU 4
333	on order	16	EMU-3
334	on order	40	EMU-3
357	on order	44	EMU-4
365	1994	41	EMU 4
373	1993	11	EMU 20
411	1958	85	EMU 4
412	1960	7	EMU 4
421	1964	144	EMU 4
422	1970	13	EMU 4
423	1967	190	EMU 4
442	1988	24	EMU 5
455	1982	137	EMU 4
456	1990	24	EMU 2
458	on order	16	EMU-4
458	on order	30	EMU-4
465	1991	147	EMU 4
466	1991	43	EMU 2
489	1983	10	EMU 1
507	1978	33	EMU 3
508	1979	31	EMU 3
373/2	1995	7	EMU 16
488/2	1973	17	EMU 2
N/A	on order	2	EMU-11
N/A	on order	8	DMU-5
N/A	on order	9	DMU-3
N/A	on order	7	DMU-3
N/A	on order	11	DMU-2
N/A	on order	55	EMU-8
N/A	on order	43	DMU-4
N/A	on order	36	BoBo Locomotive
	Total	5077	



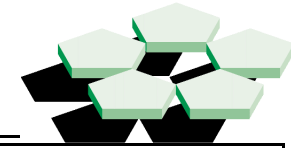
Appendix G: SPaD Case Studies

Severity category definitions - taken from Railway Safety SPAD Report for May 2002, page 25

A = SPaD occurring on Railtrack Controlled Infrastructure

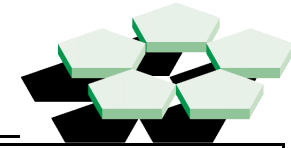
- 1 = Overrun 0 to 25 yards, overrun not exceeding overlap, with no damage, injuries or deaths.
- 2 = Overrun 26 to 200 yards, overrun not exceeding overlap, with no damage, injuries or deaths.
- 3 = Overrun greater than overlap and all overruns over 200 yards, with no damage, injuries or deaths
- 4 = Track damage only with no casualties.
- 5 = Derailment with no collision and no casualties.
- 6 = Collision (with or without derailment) and no casualties.
- 7 = Injuries to staff or passengers with no fatalities.
- 8 = Fatalities to staff or passengers.

Case 1	Inquiry reference 01/RSR/094 November 2001
Category	A, severity category- 2
Conclusion	The Driver failed to react to the cautionary aspects on Signal 1 and Signal 2 signals. Consequently, at the AWS magnet associated with Signal 3, he was travelling at 61.39 m.p.h. and was unable to stop before passing Signal 3 at danger.
Basic Causes	<ol style="list-style-type: none"> 1. The Driver was pre-occupied and distracted by an AWS fault that had been experienced some nine minutes earlier. 2. The Driver was relatively inexperienced having only been driving alone for six weeks. 3. The Driver was in contravention of the TOC driving policy by not controlling the speed of his train in an appropriate manner having experienced the correct cautionary aspects leading to Signal 3 signal at danger.
Root Causes	<ol style="list-style-type: none"> 1. Whilst the Driver 's vocational assessments had been undertaken in accordance with the TOC's regime requirements, these had not identified the Driver's propensity to become distracted through pre-occupation as he had not demonstrated that he was likely to. 2. The inspection and maintenance of the AWS equipment of unit X had not prevented its subsequent failure.
Potentially mitigated by new driver vigilance device?	Probably not.

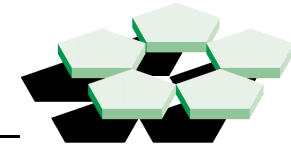


Case 2	Inquiry reference 2001/RGW/083 October 2001
Category	A, severity category- 2
Conclusion	<ol style="list-style-type: none"> 1. The Driver suffered from tiredness owing to being awoken early the previous day by his 3-month-old son. 2. The Driver suffered tiredness additionally due to this being his first night shift turn of duty and the fact that he had been unable to sleep during the day. 3. In addition, The Driver was unable to rest during his journey as a passenger from N to W as the trains he travelled on were very busy
Basic Causes	1. The train was not fitted with a DVD and therefore did not provide the additional protection to guard the Driver against tiredness.
Root Causes	1. The Driver disregarded Signal 1 (distant), failed to react accordingly and subsequently passed Signal 2 at danger without authority.
Potentially mitigated by new driver vigilance device?	Probably, however SPaD may have been mitigated by current DVD, if fitted.

Case 3	Inquiry reference 00/RSR/035 June 2001
Category	A, severity category- 3
Direct causes	1. The Driver, driving a Passenger Train, passed Signal 1 at danger, through lack of attention and/or lapse in concentration. Although he was aware that he was running on yellow aspects, he did not appear to have followed defensive driving techniques as taught to the TOC drivers. (The driver first spotted Signal 1 when it was at amber, 30s away from the signal. The signal subsequently went to danger without the driver checking until 20m away)
Contributory causes	<ol style="list-style-type: none"> 1. The driver's apparent poor driving technique was not picked up during the course of his training or assessments. Normal assessment methods will be unlikely to reveal weaknesses in concentration and attention when a driver knows he is being assessed. 2. Because of the Driver's confidence and apparent intelligence and enthusiasm, there may have been a tendency for the TOC management to have a higher view of his competence than should have been the case. The use of discretion to not award the Driver the full penalty points for earlier safety errors and therefore not categorise him as having 'A' risk status, may have contributed to management's overconfidence in him
Potentially mitigated by new driver vigilance device?	Probably not



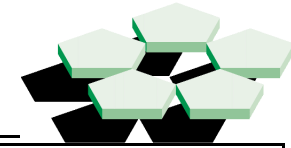
Case 4	Inquiry reference 01/RSR/052 July 2001
Category	A, severity category- 2
Direct causes	1. The direct cause of the incident was that the Driver misread Signal 1 as applying to his train. Accordingly he drove his train past Signal 2 at Danger because he believed that the proceed aspect together with the Platform 5 indication displayed by Signal 1 which had been cleared for his train to proceed from the Up Fast Line to Platform 5, applied to his train (on the up Slow Line).
Underlying cause	<p>The underlying causes can be summarised as follows:-</p> <p>1. A driver who was probably feeling below par and exhibiting lower than normal levels of concentration approaching a multi-SPAD signal which is not obviously difficult. Because of the angle of approach on the reverse curve (which may have been exacerbated by the Driver's driving position) the Driver took Signal 1 – which was displaying a proceed aspect – as his signal. Once the Driver had sighted the signal and registered the aspect and platform routing - he failed to re-check the aspect during the approach. The reasons for this lack of attention cannot be positively determined or explained. As such the dominant factors appear to be the poor alertness of the Driver and his failure to adequately re-check the signal aspect.</p> <p>2. Both these factors are as a direct result of two issues – the Driver's personal behaviour, and the Driver's Training Assessment and Briefing. The former probably rests heavily on the broken tooth and the potential cocktail of non-prescription medication the Driver took on the morning of the SPAD. The last tablets rendered the Driver unfit and his failure to declare them was unacceptable. Although the Panel do not consider this omission in any way malicious the lack of any adequate explanation as to why the correct signal aspect was not recognised – at slow speed – does invite a view that the Driver had not behaved particularly responsibly in declaring himself fit for duty that day.</p> <p>3. The poor signal sighting and checking technique must also rest heavily the Driver's Training and Briefing. The TOC should determine why despite this comprehensive programme, the Driver used sloppy techniques on the approach to a known multi-SPAD signal. Similarly, the Panel have a view that the Driver's behaviour (adjusting the sun blind) and his standing driving position probably increased the potential for the incident but these aspects must be considered within a national context of what constitutes acceptable driving behaviour. Current thinking might not consider these behavioural issues material.</p> <p>4. The Inquiry Panel do not consider that Signal 2 is a particularly difficult signal to locate or sight. Whilst sharing a gantry with Signal 1 the two signals are not applicable to adjacent lines and just two signals do provide Drivers with simple, left or right hand side options. However, as previously discussed the reverse curve does increase the potential for error.</p> <p>5. It is quite probable that the Driver actually forgot which line he was on and took Signal 1 in the belief that it was his signal. The Panel therefore strongly believe that signing Signal 2 and Signal 1 with line designation boards is a priority and should be implemented urgently. The decision by the Risk Assessment Panel in December 1999 appears inappropriate. Had the boards not been vetoed, it is probable that this SPAD would not have occurred.</p>
Potentially mitigated by new driver vigilance device?	Probably not



Case 5	Inquiry reference 01/RMI/301 August 2001
Category	A, severity category- 4
Direct causes	1. The Driver in charge of the Train passed Signal 1 at danger believing it to have exhibited a yellow aspect, as a result of initially sighting the signal when sunlight reflected on the signal lenses and before the red aspect beam came into his line of vision. He then failed to observe the aspect as he got nearer to the signal.
Contributory causes	1. The sighting of the signal and the alignment of the lenses and light beams on Signal 1 was not ideal and created the conditions in which it was possible for the driver to make the error. No proper record of Signal Sighting Committee recommendations prior to the incident for this signal were available. The AWS train borne equipment may not have operated correctly to give a further reminder to The Driver of Signal 1's restricted aspect, although from tests subsequently carried out, this seems unlikely.
Potentially mitigated by new driver vigilance device?	Probably not

Case 6	Inquiry reference 2001/RGW/060 June 2001
Category	A, severity category- 2
Conclusion	
Basic Causes	1. Dust from the cab ventilation equipment blew into The Driver's eye and caused him to sneeze. This distracted him and caused a loss of concentration between the single yellow received at Signal 2 and the red aspect at Signal 1.
Root Causes	1. The signal spacing between Signal 2 and Signal 1 is almost unique in track circuit block / colour light signalled areas. The time taken for a train to traverse this section after receiving a single yellow aspect creates a potential for concentration loss by the Driver.
Immediate causes	1. The train passed Signal 1 signal at danger due to the Driver disregarding the single yellow aspect displayed in Signal 2 at a Junction. The Driver failed to control the speed of his train in accordance with the defensive driving policy on the approach to Signal 1 at danger due to a lack of concentration. The Driver activated the cab ventilation equipment between receiving a single yellow aspect and the final approach to Signal 1 at danger.
Potentially mitigated by new driver vigilance device?	Probably not

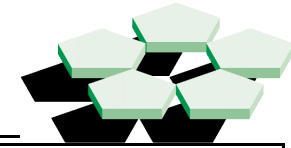
Case 7	Inquiry reference 2001/RGW/052 June 2001
Category	A, severity category- 1



Basic Causes	<ol style="list-style-type: none"> 1. The Driver failed to comply with the TOC's Defensive Driving Policy in accelerating in notch seven to the full line speed of 40 mph after departing from the station with a single yellow aspect in Signal 1 2. The Driver remembered the green aspect displayed at Signal 2, having stood at that signal for a number of minutes and observing it step up from red to green.
Root Causes	<ol style="list-style-type: none"> 1. Whilst undertaking station duties at the Station, the Driver was distracted from the single yellow aspect displayed in Signal 1 by crossing to the right hand side of the cab to check whether the train was fully berthed in the station.
Immediate causes	<ol style="list-style-type: none"> 1. The Driver disregarded the single yellow aspect displayed in Signal 1 (and thus did not anticipate a red signal aspect at Signal 3, which the Driver passed at danger).
Potentially mitigated by new driver vigilance device?	Probably not

Case 8	Inquiry reference 2001/RGW/091 October 2001
Category	A, severity category- 4
Basic Causes	<ol style="list-style-type: none"> 1. Position light Signal 1 located at ground level thus becoming less conspicuous to drivers. 2. Position light Signal 1 partly obscured by foliage thus diminishing it's visibility 3. Position light Signal 1 not of new optimised LED type and did not have the more easily interpreted two reds to indicate danger. 4. The Driver developed the habit of staying in the siding with Empty Coaching Stock until almost departure time from the station, regardless of whether the signal was cleared, or not. This led to departure time becoming a more significant to the Driver than the signal itself.
Root Causes	<ol style="list-style-type: none"> 1. Youths intent on causing mischief hanging around the station leads to some drivers remaining in the sidings when position light Signal 1 shows a proceed aspect in order to avoid confrontation at the station.
Immediate causes	<ol style="list-style-type: none"> 1. The Driver disregarded Signal 1 at the Turn Back Siding, passed it without authority and consequently derailed the Train (Empty Coaching Stop) at the points
Potentially mitigated by new driver vigilance device?	Probably not

Case 9	Inquiry reference 01/RSR/115 December 2001
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Category	A, severity category - 2
Conclusion	1. The Driver failed to check the signal aspect on Signal 1 resulting in the signal being passed at danger
Basic Causes	<ol style="list-style-type: none">1. A change in driving technique and greater acceleration resulted in more traction current being drawn by the unit. This, in conjunction with frost on the conductor rail increased instances of arcing that led the Driver to believe that the shoe gear had become damaged.2. Having reached a clear understanding that the signal was to be replaced to danger, the Driver failed to deploy the Driver's Reminder Appliance.3. The Driver allowed himself to become distracted by de-training the passengers and his belief that the trains shoe gear had become damaged.
Root Causes	<ol style="list-style-type: none">1. The Driver briefings undertaken by the TOC did not highlight the importance of recognising the difficulties, which may be encountered while driving during conditions where the conductor rail may be contaminated by frost or snow.2. The TOC had not briefed their drivers on the deployment of the DRA when the signal in advance of their train is to be replaced to danger.
Potentially mitigated by new driver vigilance device?	Probably not

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