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System Analysis on Driver Monitoring System for Mainline Railway

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Abstract

Driver alertness and attention are factors in nearly 50% of Signal Passed At Danger (SPAD) events that could lead to railway accidents. My research aims were to carry out a system analysis on increasing the capability of the existing vigilance system for UK mainline passenger trains to include active detection and actuation based on driver's alertness. The current vigilance system has existed for a long time in UK railway history, and requires optimisation of its original capability. The current vigilance operation can be tricked, isolated, or become a routine gesture. There is a delay time of 60s with 5s action time for the driver to reset the 'lack of activity' trigger, which is far too long for trains operating at a typical line speed of 125mph. This new capability is efficient in reducing the reaction time of detection on driver's falling asleep by 97% (from 65s to 2s) for drivers who cannot be woken by audio alarm, and by 93% (from 30s to 2s) for drivers who can be woken up by a beeping sound. Additional functionalities of the proposed design include detecting early signs of falling asleep, microsleep and eyes-off-road, both intentional and unintentionally.

1 Introduction

1.1 Context

Train drivers bear safety-critical responsibility for hundreds of passengers on mainline routes, especially for high-speed intercity trains.

Among all fatal train collisions and derailment accidents in Europe, human error contributed to three quarters of these accidents, with a significant proportion caused by train drivers (Evans 2017). Within Signal Passed at Danger (SPAD) events[1], 49% were caused by driver alertness and attention factors, with an additional 4% involving drivers being incapacitated or asleep (RSSB 2021).

Drivers are responsible for noting of any danger on the line, such as obstacles, which is challenging when the weather is dark or foggy, or when the driver become drowsy due to lack of sleep associated with shift-work pattern. Most drivers try to carry on working no matter how drowsy they are. 55% of drivers deal with tiredness by caffeine input (RSSB 2005a), which is just a temporary measure.

[1] Note: Appendix B provides a short table of acronyms as a reference for non-railway industry readers.

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The existing Driver Safety Device (DSD) monitors drivers' alertness in a passive way by either a deadman's switch or an acknowledge button with a prolonged, one minute, delay time before actuation. Periodic acknowledgement of the button easily becomes a routine gesture. It does not detect microsleep nor distraction. These devices can even be intentionally tricked or deactivated.

A recent fatal accident caused by a driver who experienced microsleep occurred in Croydon, causing 7 passenger casualties, which led to an industrial review for railways. Since then, an anti-sleeping "Guardian Device" entered trials in UK tramways (Townsend 2019), and eye-tracking glasses went under review for ETCS[2] trains (SMI 2014).

Previous research is outdated, and does not consider the capability of the current vigilance system as a whole. This paper thus focusses on improving the capability of the driver monitoring system such that it is fit-for-purpose; it lays the foundation for a future design process from an all-round perspective. It should also be of interest to those in other industries in which continual operator vigilance is important.

1.2 Aims & Objectives

This paper aims to carry out a system analysis to build a foundation for the development of an increased capability of the driver vigilance system for UK mainline passenger trains, to include active detection and actuation based on driver's alertness.

The objectives are to:

- Understand stakeholder needs within the system boundary;
- Establish high-level requirements for both functional and non-functional aspects, including Measures of Effectiveness (MoEs) on usability;
- Develop sub-system measures of performance with traceability to high-level requirements;
- Identify critical interfaces and functional limitations of the system; and
- Explore short-term and long-term potentials of the monitoring system development in the UK.

1.3 Scope

UK mainline railway passenger service trains are chosen as the type of transport for analysis. Metro drivers work in a controlled environment and arrive at a stop every few minutes. Metro drivers are thus less likely to lose awareness due to the higher need to focus on frequent operation tasks.

This paper is applicable for diesel and electric traction trains where drivers work alone and have comparatively modern and comfortable seats. When driving aboard a steam locomotive, a driver is less likely to fall asleep (RSSB 2014).

The proposed driver monitoring system considers only trains in running mode that are moving during normal passenger service. Other scenarios, such as degraded mode where redundancy of main components fails, shunting mode, and emergency situation or service disruption are excluded, because the processes involved are more complicated in a less controlled environment.

[2] European Train Control System

A system analysis approach is adopted in this paper to study driver monitoring systems from a range of perspectives. This is not a comparison review between off-the-shelf devices available on the market. Cost and commercial aspects are excluded.

The analysis focuses on the system front end, including sensing and actuating functions with direct interaction with the users. Backend functions, such as perceiving and decision making, belong to software development and are only discussed at a high-level. Details of how data is stored and manipulated are considered out of scope.

Drivers can suffer from "highway hypnosis" where they lose memory for certain period (RSSB 2014). This state of mind is often encountered with driving on repeated routes. It is a mental stage that can only be detected by brainwave activities, and thus is not studied in detail.

1.4 Method

Background research on the current human factors and safety procedures were reviewed using available resources and reports from institutions and government agencies. Literature review on existing driver safety system was conducted based on conference proceedings, reports from European Union agencies and previously published articles.

Technical review on existing technologies adopted by various industries were investigated through studying journals and academic research papers published by universities, and commercial catalogues.

System analysis using a capability systems engineering approach was adopted. Ordinary office tools such as Microsoft Word, Excel and Visio were used, as well as purpose-built toolsets such as Sparx Systems Enterprise Architect for developing matrices, diagrams and modelling (Graves 2009).

2 The Importance of Vigilance

2.1 Background

Human factors contribute to 75% of fatal train accidents in Europe (Evans 2017). Train drivers' errors, such as SPADs and over-speeding, contribute together to 44% of the total number of train collisions and derailments (Evans, 2017).

A recent study found that 49% of those SPAD incidents are due to drivers' inattentiveness and lack of alertness (RSSB 2021). Another 4% even involve drivers being incapacitated or asleep. According to Reason (1990), human error, including attention distractions, is one of the reasons leading to occurrence of accidents.

Train drivers work on shifts with either early starts or late finishes at midnight. A survey in Canada (Nicol and Seglins 2014) reported that 3 out of 4 train operators admitted that they feel exhausted and encountered "nodding off" while driving. Tiredness due to high workload and boredom due to lack of tasks required are undesirable extremes created by the nature of train driving. Distraction and fatigue are the most common causes of driver's error.

As part of the research, a driver's cab walkthrough was originally considered one of the good methods to understand the driver's operation. However, due to the recent pandemic physical visits were not allowed during the period of when this paper was produced.

Eventually, I interviewed a train driver[3] who had worked for one of the largest UK Train Operating Companies (TOCs) for about four years to understand their work shifts pattern, and challenges faced in their daily work[4]. He expressed that he easily feels tired after a few days of shifts with early-starts time, or late finish. Drivers can report sick to a Driver Resource Manager (DRM) if needed, however, in reality they tend to just "*drink coffee and get on with it*". Tiredness can sometimes become a challenge, especially when there is no person to talk to, and the consequence might even be that he misses a station.

In fact, a separate survey found out that caffeinated drinks were used as a method to deal with fatigue in UK railway by 50% of the train drivers, and around 5% used caffeine tablets (RSSB 2005a).

2.2 Existing Technology

To ensure that drivers are alert and fit for work, driver's vigilance systems are a complementary safeguard to train protection and control systems (RSSB 2014). SPADs are effectively managed by a Train Protection and Warning System (TPWS) that applies emergency brakes automatically (NRIL 2017).

The DSD, or deadman's switch, has been adopted in Great Britain on locomotive driving cabs for over 50 years (RSSB 2014). All manually driven trains are required to be equipped with a dead person's device, or vigilance system, for mass transit railway and high-speed trains in UK and Europe; see BS EN 13452-1:2003, BS EN 15734-2:2010 and (EU) No 1302/2014. The system checks the driver's vigilance to detect any loss of consciousness with linkage to the train's automatic stop function. If no pressure is applied on the pedal or the handle, the brakes are applied after a pre-set time period bringing the train to a stop.

The vigilance system function is achieved by collecting data from the DSD, deadman's handle or foot pedal, Automatic Warning System (AWS) acknowledge button, and movement of the power and brake controller. The driver's activity is monitored by also noting their action on the Train Control and Monitoring System (TCMS) as per BS EN 14033-1:2017.

A Driver Vigilance Device (DVD) steps in when the DSD is not reset by the driver within the given timeframe. Designed according to standard BS EN 14033-1:2017, and the Locomotive & Passenger Rolling Stock Technical Specification for Interoperability (LOC&PAS TSI)[5], the required operating principle is based on a multiple step process starting from monitoring the driver's vigilance (See Figure 1, which is based upon the standard and TSI just referenced).

If no action is detected for 5 seconds, vigilance monitoring starts. After 20 seconds of inactivity, a visible alarm flashes, followed by ringing of the bell (EKE-Electronics Ltd.

[3] The interview with the train driver was conducted during 12th to 30th July 2019 via Facebook Messenger, an informal social media platform for communication.

[4] Note that evidence from a single informal exchange of messages with one train driver does not constitute a reliably accurate portrayal of the effects of fatigue on the driving community.

[5] See (EU) No 1302/2014.

2017). During the typical 5 to 7-second action time the foot pedal must be released and depressed in order to stop the countdown. If delay time exceeds 60s, automatic stopping of the train is involved; see BS EN 14033-1:2017, GMRT2185 and (EU) No 1302/2014. A message is sent to the signalling centre via GSM-R[6] radio system (The Train Guard 2014). An extraction of the relevant clauses can be found in Appendix A.

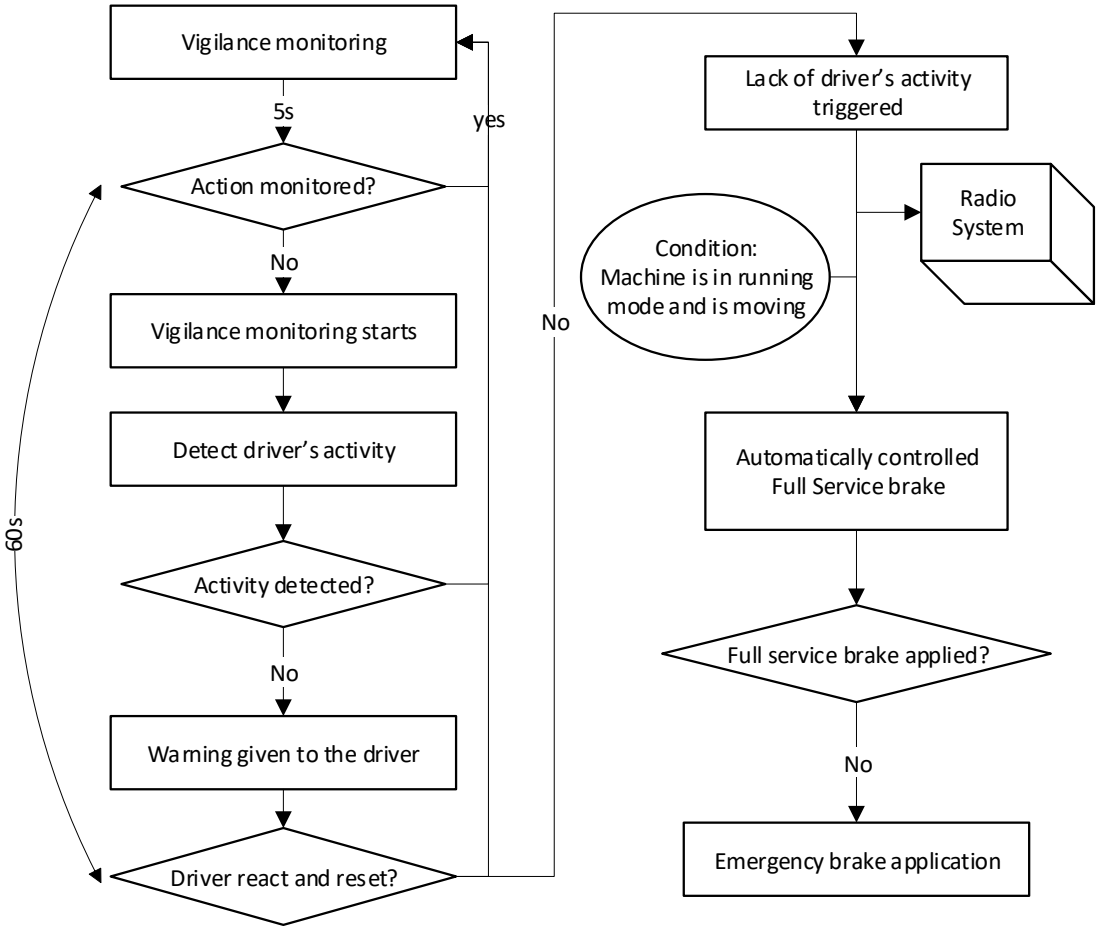


Figure 1 ~ Logic Flow of Current DVD Working Principles

An automatic watch device, as part of the DSD fitted on control panels used in UK mainline railway, include a push-button, a pedal on the floor, an acoustic electric warning device, and a warning light. The system also includes multiple speed measuring devices and a timer device (DEUTA-WERKE 2019). The vigilance system is wired to both the vigilance isolation switch and the vehicle brake circuit.

2.3 Inherent Shortcomings

The current requirement of 60s for determining lack of driver's activity is considered too long compared to the speed of modern trains, and the reaction time required for other driving cab controls. UK mainline trains, such as the Pendolino Class 390, runs at 125mph (201km/h) (de Castella 2015) and so travels 280m in 5 seconds.

[6] Global System for Mobile Communications-Railway

Longer reaction time is related to driver fatigue level. The delay time of a minute is also far longer than the required driver's reaction time for acknowledging a safety system massage, such as TPWS horn, which is 2.5 seconds. This reaction time for the train protection system was set to be short enough to avoid an error leading to a braking application (El Rashidy and Van Gulijk 2016).

The device can be isolated during operation if it fails, only if a trained Guard or second driver is present to operate the emergency brake if the first driver loses consciousness (The Train Guard 2014). The driver can isolate the driver's vigilance equipment when the warning cannot be reset (RSSB 2018).

A deadman's pedal is not reliable on detecting driver's attentiveness; for example, some drivers who find them annoying would override the system illegally, freeing themselves for other activities. To overcome its weaknesses, a vigilance control, the DVD, was fitted as an automatic watch device. Vigilance buttons are to be pressed periodically and can be activated to remind the driver when stopping at a red signal. However, DVD is also not fully effective because driver can disable it without knowing (RSSB 2014).

For certain forms of sleep, such as microsleep, which occurs when the driver becomes inattentive, the deadman's handle does not in all cases result in the train being stopped. Microsleep has been the immediate cause of a number of derailment accidents in history. One example was in April 2003 at Apeldoorn in the Netherlands (RSSB 2014) the train was fitted with a deadman's handle, however that did not result in the train being stopped.

2.4 Accidents

In 2016, the Croydon tram collision led to 7 people killed. The Rail Accident Investigation Branch (RAIB) report noted that, "*In common with most trams and trains in the world, there was no device fitted that was capable of reliably detecting drivers' loss of awareness*" (RAIB 2016).

The accident report revealed that, although the driver had already lost consciousness, there was still a downward pressure applied on the Traction/Brake Controller (TBC) while he approached the junction. The fact that the DSD has not been disabled (RAIB 2016) indicated that the DSD system had an inherent design defect.

Another catastrophic accident, the Santiago de Compostela derailment, occurred in 2013 and led to eighty fatalities in Spain. The driver claimed that he was distracted as he was talking on the telephone with staff at the control centre (Langer 2016). Another incident happened in the Hunter Valley, Australia in August 2013 where two coal train drivers employed by Pacific National disabled the vigilance device and read newspaper while driving (RSSB 2014).

Based on the above, it seems that neither the deadman's switch nor the driver reminder appliance can avoid microsleep, or intentional distraction such as reading a newspaper or browsing mobile telephones. These accidents suggest that the current safety devices are out of date, and need to be revisited and re-designed to meet the required safety standard.

After the Croydon Tram crash, an anti-sleeping device, The Guardian Device, was developed to be installed to track driver's facial features real-time to recognise events such as microsleep and distraction (Townsend 2019).

Although light rail driving relies on line-of-sight, it still raises the question whether mainline trains require a similar device that monitors driver's fatigue and distraction. This paper therefore looks at how one can improve the capability of the current vigilance system.

3 Literature Review

3.1 Driver Inattentiveness

3.1.1 Driver Tasks

Train drivers perform several tasks during their shifts. After a train's departure, they operate the train on the set route, respond to signals, obey speed restrictions, and comply with a common set of railway rules and regulations, which are provided by the rail company or their regulators. Additionally, drivers have to stop at the stations on the route and keep to the timetable as strictly as possible. They also stay in contact with control rooms, station staff, and on-train colleagues to report any problems on the line or train (Kyriakidis 2013).

Cognitive ability of drivers is exceptionally important for road and train drivers. Both require high attention, visual perception and reaction ability (Guo et al. 2019). Train drivers work under a high level of stress due to more stringent safety requirements, and they are responsible for hundreds of passengers' lives. Yet train drivers follow tracks, without the need of changing lanes or using steering wheels (Guo et al. 2019), thus they are more susceptible to loss of concentration due to the routine driving tasks.

3.1.2 Levels of Driver Readiness

Driver's readiness can be categorised into different levels of arousal, as in Table 1, which is derived from Whitlock (2002). Level 5 indicates the driver is at full alertness and is performing all necessary operating tasks. Level 4 means the driver is multi-tasking but is still sufficiently alert. For level 3, although the driver is sufficiently alert, he or she is not attending to the train operating tasks. Levels 2 and 1 of deficiency in driver's readiness are what this paper is mostly interested in. Drivers at level 2 are awake, but drowsy and not sufficiently alert. Drivers at level 1 are incapacitated, asleep or dead.

Table 1 ~ Level of Driver Readiness in Decreasing Order from 5 being Attentive to 1 being Inattentive

Level of Arousal	Not Inappropriately Time-sharing between Operating Tasks	Attending to the Train Operating Tasks	Sufficiently Alert	Alive and Awake
5	✓	✓	✓	✓
4	×	✓	✓	✓
3	×	×	✓	✓
2	×	×	×	✓
1	×	×	×	×

3.1.3 Fatigue

To understand how to detect driver's fatigue, it is critical to understand the explicit signs that occur when a driver feels extremely tired. A fatigued driver shows symptoms such as

repeated yawning, feeling irritable, delayed reactions, daydreaming, difficulty in keeping the eyes open, shallow breathing (Meiring and Myburgh 2015) and blinking rate reduces (Haq and Hasan 2016). Increase in Percentage of Eye Closure Over Time, excluding the time spent on normal closure, is a wide known measure of the drowsiness (Dinges et al. 1998) that characterises driver fatigue (Ji and Yang 2002).

3.1.4 Distraction

Distraction can be visual, cognitive, auditory, or biomechanical (Meiring and Myburgh 2015) or a combination of these stimuli. Modern trains are equipped with a Driver Advisory System (DAS) with enhanced functionality. Increased usage of information display units, such as DAS on energy-saving suggestions, causes drivers to be required to multitask while driving, leading to potential distraction.

We can thus predict that the common methods for detecting driving fatigue and distraction are monitoring of eyes movement, head tilt and position, facial expression, and change in heart rate (see Figure 2, which is based on Meiring and Myburgh (2015) and Haq and Hasan (2016)).

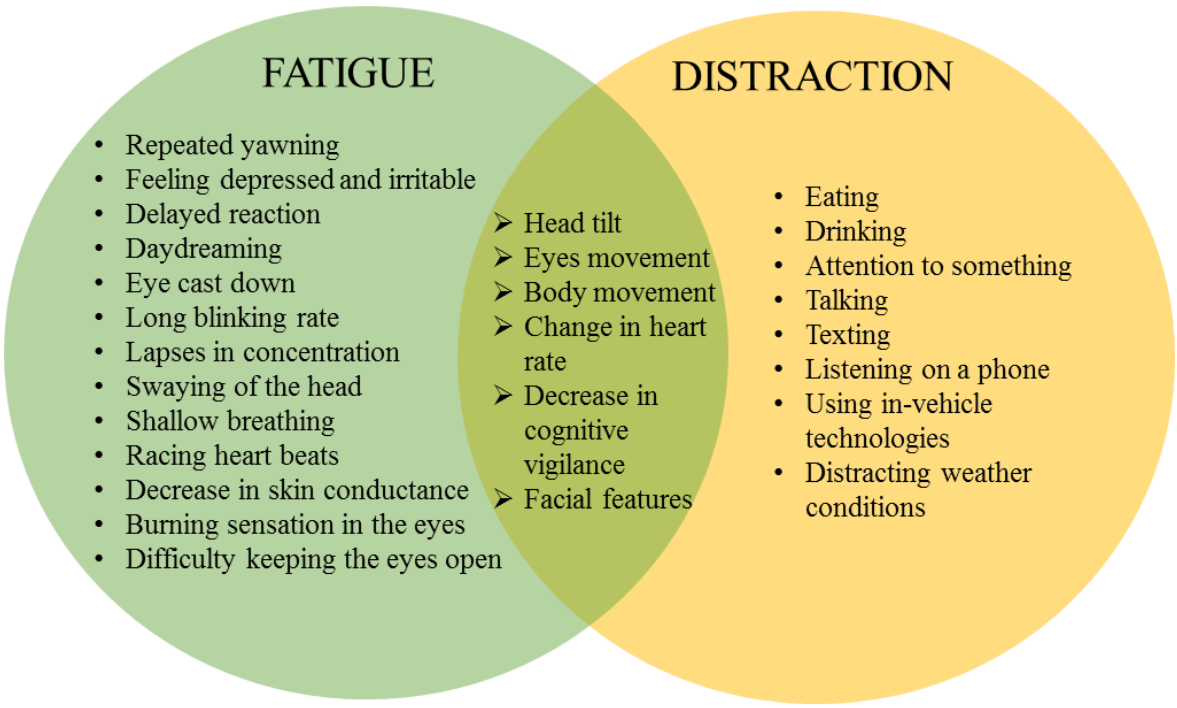


Figure 2 ~ Common Characteristics of Fatigue and Distraction

3.1.5 Highway Hypnosis

When driving on repeated routes, drivers can suffer from highway hypnosis, wherein they lose memory for certain periods (RSSB 2014). There is minimal safety hazard for road vehicles in this scenario, because the driver can still react to stimulus (Commissaris 2019). There is a certain degree of safety implication for railway drivers to lose location awareness, because they rely on route knowledge for interpretation of signals and signs ahead (Whitlock 2002).

Studies on the correlation between brainwave activity and drivers who ‘zone out’ are undertaken in order to create a warning system (Magazine Monitor 2013). Although

considered as one of the distracted driver's phenomena, highway hypnosis is a mental stage, rather than possessing physical symptoms, therefore is not discussed in detail in this paper.

3.2 Previous Work

The Rail Safety and Standard Board (RSSB) carried out a detailed research on DVDs (Whitlock 2002) nearly two decades ago. Thirteen technologies were explored using feasibility criteria with three technologies deemed applicable, but yet to be used in the railway industry. The scientific criteria provided were at qualitative level where they cannot be measured and verified.

Another study regarding driver alertness monitoring system was issued for ScotRail (RSSB 2014). It was concluded that there are concerns over different kinds of devices, such as the intrusiveness of a camera. Train controls, including AWS, TPWS and eventually the European Railway Traffic Management System (ERTMS). with existing vigilance systems already provide a certain degree of protection. Further development is needed to justify the balance between vigilance system and control system.

The above studies only compared different commercial-off-the-shelf products. Another paper on fatigue detection technologies provided an all-round analysis of driver-state monitoring systems, however, it focus on road vehicles rather than rail (von Jan et al. 2010).

This paper therefore conducts a comprehensive analysis considering the whole problem using systems engineering approach with measurable requirements that can be verified.

3.3 Monitoring Systems

3.3.1 Rail

The European Union Agency for Railways explored the potential applications of measuring the level of competence of train drivers by monitoring eye movements to observe their behaviour (D'Agostino 2016).

The Croydon, UK, Tram crash in November 2016 killed 7 passengers and caused serious injuries to many others. The RAIB recommended safety measures, including installation of a monitoring system to detect the onset of fatigue or distraction of tram drivers (RAIB 2019).

To improve safety after the 2016 Croydon incident, London Trams and Tram Operations Limited announced the implementation of an anti-sleeping tool called "The Guardian Device" for tracking symptoms of real-time fatigue and distraction of tram drivers (Townsend 2019). When these symptoms are detected, an audio alarm and seat vibration are activated to alert the driver. A few seconds prior to the alarm, the recorder is switched on to allow incident investigation. Techniques involve tracking of micro-movements of a driver's eyes, head and facial expressions to identify driver's behaviour.

The Croydon tram was fitted with Guardian driver monitoring device 8 months later, as a result of the accident that happened the previous year (Booth 2017). The device is composed of four hardware components, namely the in-cab guardian sensor, a forward-facing camera, a computer/controller, and a vibration motor (Seeing Machines 2019). The installation is pictured in Booth (2017).

The infrared sensor can detect through sunglasses; the system assesses drivers' fatigue and distraction by eye, face and head position. An audio alarm goes off when the driver is looking at the sides for certain period of time. The seat vibrates when eyes are closed for a few seconds, which indicate that the driver is under fatigue.

3.3.2 Road

Technologies for predicting driver's alertness are evolving in road vehicles. Singapore Mass Rapid Transit trialled a biometric device to collect bus drivers' behaviour for analytic purpose, identifying high-risk drivers (NEC 2014). The company engaged data scientists to observe the drivers' eyes and concentration levels. However, the bus company did not allow the use of cameras, so instead they used telematics data from road performance data and driver training records to predict the bus drivers' behaviour (Griffith 2017).

Facial recognition technology developed by Microsoft was adopted in Bangkok, Thailand, to establish a programme called "AI for Road Safety". Drowsiness (evidenced by eyes closing and blinking time) and distraction (evidenced by yawning, eyes-off-road and mobile device using), detected by computer vision, are sent for interpretation using machine learning (Microsoft 2019) to alert drivers and to inform risk Key Performance Indicators.

3.4 Monitoring Technologies — Sensing Devices

3.4.1 Video-based Sensors

Images of the driver are captured for analysis through computer vision processing to identify driver's behaviour and events. These technologies can be categorised into eye movement, facial features, and head position detection.

Eye Movement: Eyes blinking and position are used as the major detection means of driver state in the automotive industry. Looking away for at least 1.8s can be considered a driver visual distraction for road vehicles (Tango and Botta 2013).

The sensor is integrated into the drivers' cab of the vehicle. The advantage of this method is that it does not have to be a wearable device, nor even have any physical contact with the user. As a result, the accuracy depends highly on the maturity of the image processing technology. To ensure high reliability and sensitivity, there needs to be robust algorithms to avoid false alarm. It also needs to overcome different lighting conditions and physical characteristics, such as eye colour and spectacles. Therefore other physiological measures are also used to provide additional confidence and indications (Tango and Botta 2013).

The Guardian device uses infrared sensors, such that it can see through sunglasses (Seeing Machines 2019), and in the dark. The amount of infra-red light is so low that it is less than 2% of the sunlight that reaches the driver's eyes and face (Murray 2017).

Apart from remote sensing, eye tracking glasses are also available for drivers to wear, such that their eye movements can be tracked with a wearable pair of glasses. SMI Eye Tracking Glasses are equipped with insertable sunglasses and corrective lenses (SMI 2014). However, this is a wearable device that may become an extra burden to drivers who do not usually wear corrective spectacles.

Facial Features: Driver drowsiness level can be measured using facial expressions, including inner and outer brow rise, yawning, jaw drop as well as lip stretch (Doudou et al. 2018). Behaviours including yawning and talking on the telephone can be captured by the feature extraction technique.

Head Position: Head tilting down and head nodding are signs of drowsiness (Doudou et al. 2018). Head position detection is often used in combination with eye movements as seen in the Guardian device implemented for the Croydon trams (Seeing Machines 2019). Head nod events alone are not a good indicator of drowsiness, because microsleep occurs without head nods (Whitlock 2002).

No matter what the target objects are, either they are the eyes or the head, camera-based technologies capture images of a person's face, therefore are intrusive in nature, and can make one feel that they are under surveillance. They also require robust algorithms to deal with variable sunlight, driver's spectacles, and other "noise sources".

3.4.2 Telematics Recording

Telematics recordings are of vehicle-based sensors that detect a train's dynamic data, such as acceleration and speed. Research found that there are correlations between a driver's alertness level and the speed of the vehicle, the acceleration, and pressure on the acceleration pedal. Drowsy drivers tend to increase acceleration (Doudou et al. 2018) and increase speed variability (Dorrian 2008).

A telematics system has been implemented for bus drivers that notifies them when they accelerate or decelerate quickly, or overspeed for a prolonged period. The system is able to identify high-risk driving events using data collected from driving behaviour and historical route-related information (NEC 2014).

Telematics records can be analysed and used to improve driving performance in a similar way in the railway context. The Institution of Railway Research (IRR) studied the applicability of assessing driver competence performance using real-world On-Train Monitoring Recorder (OTMR) data. Originally recorded for accident investigation purpose, these data include indicators such as Emergency Bypass Switch, Driver's Reminder Appliance and Driver reaction time (El Rashidy and Van Gulijk 2016).

3.4.3 Physiological Signals Sensors

Physiological signals from human organs such as brain, eyes, muscles, and heart are collected to determine wakefulness and fatigue level (Doudou et al. 2018). The advantages of physiological based technologies are that they are more reliable and accurate, and have lower level of noise and artefacts. It is also possible to detect early signs of drowsiness, and thus give alert prior to any accident happening (Doudou et al. 2018).

Skin Conductance: An electrodermal wristwatch operates by measuring skin conductance response. The Vigilance Telemetric Control System (Neurocom 2019) uses galvanic skin resistance to predict driver's alertness. The Steer wearable device (Created Mode 2020) also uses electrodermal activity, but is worn on the finger rather than the wrist. Steer warns the driver when skin conductance decreases, which indicates fatigue. It was later found that the particular electrodermal activity monitor worn was not responsive enough to be able to detect sleepiness when the subject falls asleep.

Respiration Rate: Respiration rate sensing device measures respiratory effort, nasal and oral airflow, and blood gas (Doudou et al. 2018). An anti-sleep driver seat sheet (Toto 2012) has built-in pulse monitoring and respiration sensors installed. This Sleep Buster originated from Japan; it measures the driver's bio signals every 18 seconds and can warn drivers 10 minutes before they fall asleep. This device is yet to be proven on the market. According to academic research, these sensors are difficult to use in real-time due to a delay in detection of sleepiness (Tango and Botta 2013).

Heart Rate: Cardiac activity can be monitored through electrocardiography and blood pressure signals. These technologies are used in lie detectors, or polygraph, by the police and other agencies, but are not common in society. Sensed every 2 seconds, when heartbeat is detected to be lowered by 10 units, the STEER wearable device warns the driver about increase in fatigue level (Created Mode 2020).

Brain Signals: Detecting brain signals by a brain waves cap (Deayea 2019) and wireless wearable electroencephalograph (Zhang et al. 2017) are plausible methods; they need to be worn but do not accommodation religious head-dresses — or drivers' uniform hats.

To summarise, physiological signals sensors require certain amount of physical contact with the user. These technologies are thus more intrusive and invasive, and are more difficult to use (from the point of view of the user) compared to vehicle and telematics sensors (Doudou et al. 2018). Built-in sensors, e.g. installed inside the driver's seat, are less invasive and provide early warning, however, this technology development has not been promoted to widespread usage yet due to a low response rate.

Note that physiological sensors do not detect distraction, unlike camera-based sensors which serve both purposes for drowsiness and distraction identification.

3.4.4 Mobile Telephone Detectors

To prevent drivers from being distracted, usage of mobile telephones in the cab is restricted (ORR 2010). Mobile telephone detection technologies can be used to ensure compliance with regulations. These devices can distinguish signals from mobile telephones and from the train and notify a control centre when mobile telephone signals are detected (Wi-Tronix 2016).

3.4.5 Cognitive Vigilance Device

In Australia, drivers are asked to carry out cognitive task, e.g. mathematical calculations, to confirm their cognitive vigilance (RSSB 2014). This type of vigilance approach, however, imposes distraction to the drivers to respond to their operating task. A report concluded that these devices are only suitable for train driving with high automation where trains travel at fixed speed for prolonged period, which is not in case in UK and Europe (RSSB 2014).

A study also suggested that secondary tasks are not suitable to be used as DVDs because the drivers get used to the task, and do not stay alert anymore after a period of time (Dorrian 2008).

3.4.6 Summary

Video-based sensors can be used for both distraction and drowsiness detection. These are more suitable than physiological signals sensors, of which the majority are only effective

for alertness prediction. Physiological sensors outperform the visual techniques on accuracy; however they lack sensitivity and inhibit drivers' operation as they are mostly wearable. Telematics recording can be used as an extended function for estimating driver performance. Mobile telephone detectors can be fitted in the cab to verify the use of mobiles, without interfering with drivers' privacy.

3.5 Monitoring Technologies — Actuating Devices

3.5.1 Visible

Flashing lights and warning messages on a display are common types of warning system. Drivers' eyes are closed when they lose awareness, and thus are less sensitive to light level changes. Therefore, visible alarms can only be used as an initial reminder, as illustrated with the STEER wearable device (Created Mode 2020), but not the main form of alarm to restore wakefulness.

3.5.2 Audio

Audio alarms exists in multiple forms, such as a buzzer or an announcement. Drivers easily get used to multiple ringing and repeated messages. Recorded audio announcements can be used to remind a driver of the importance of keeping vigilant and to seek for a break if necessary. Such a recording can be embarrassing if heard by passengers, which can ultimately affect the TOC's reputation.

Another type of audio reminder is a telephone call from the control centre. Drivers talking on the telephone can be easily distracted, as in the Santiago accident in Spain (Langer 2016). It is thus deemed not suitable as a vigilance alarm during normal operation. It can be used as a confirmation from a driver's manager at the control centre to check if the driver needs a break, and to assist with necessary arrangements for stopping of the train.

3.5.3 Vibration

Various forms of vibrating alert technologies are available on the market. A fatigue detection system research project used a massage chair for experiments, then designed driver seats with built-in vibration motor (Zhang et al. 2017). Vibration seat technology is also used in the Guardian device on the Croydon trams (Seeing Machines 2019).

The actuating device can be worn on the driver's arm as in STEER wearable device (Created Mode 2020), or on fingers as in Anti-sleep alarm (Stopsleep 2020). These wearable devices are not preferred, because they hinder body movements when performing driving tasks.

3.5.4 Electric Shock

Electric shock has been used as an alarm clock to train people to wake up at a particular time. Eventually people develop a habit of waking up on time, probably due to a fear response. Shock Clock invented by Pavlok has a three-step alarm starting with vibration, then beep and finally "zap". This technology has then been adopted in road vehicle for drivers such as the STEER wearable device (Created Mode 2020). Electric shock technology is controversial, especially if becomes mandatory, because of ethical issues.

The voltage, however mild, causes discomfort, and therefore is unacceptable for the purpose of maintaining a train driver's vigilance.

3.5.5 Summary

Visible and audio alarms are basic forms of warning used in the existing vigilance systems, together with automated application of brakes as the last resort. Audio alarms can be used to alert distracted drivers when they look away for more than 2 seconds. Visible alarms are less useful for distracted drivers who may be looking away from the flashing light. A buzzer sound is better than a recorded message, as it serves the purpose without the passengers realising the associated meaning.

Microsleep occurs typically between 0.5 to 30 seconds (Poudel et al. 2014). Drivers who experience microsleep do not react to sound or light (Created Mode 2020). It would be beneficial to install vibration alarms for drowsy drivers to increase their wakefulness. The control centre can give the driver a telephone call to establish whether the driver is fit to continue.

3.6 A Driver's Opinion

From an interview with a Thameslink driver, he felt that the Guardian device on Croydon Trams was an invasion to drivers' privacy, and felt like this is a device for surveillance purposes. The drivers' union has also argued that the fundamental issue needs to be dealt with first, which is long shifts and health regimes, before such implementation(LBC 2018). The drivers are concerned with long periods of time being exposed to infrared beams. Some drivers complained of headaches, dry eyes, and blurred vision while being illuminated by infrared beams (Murray 2017). However, the spokesperson from Seeing Machines claimed that their infrared beam has no health risks to humans.

In a customer opinion survey, it was found out that a doze-off alarm is thought more important than a fatigue detector, and there is a high customer acceptance of technology in Germany (von Jan et al. 2010). The users' needs have to be satisfied to ensure that the system provides tangible support.

Train drivers' opinions are key in any modification to the drivers' cab. There are three main train drivers' unions in the UK, which have tens of thousands of members. They are namely RMT, ASLEF and TSSA [7]. Changes made to a train driver's working environment has to go through Rail Delivery Group (RDG) and representatives from these trade unions.

3.7 Ergonomics

Human factors aspects of the driver's seats associated with modifications to install a built-in vibration motor need to be assessed to ensure that the seats remain adjustable to accommodate a range of body dimensions.

For video-based equipment during operating tasks, it is fundamental to ensure the field of vision of the camera covers the range of movement of the driver.

No foreseeable changes to the cab workstation layout are identified, except for the new equipment that are to be fitted in the cab, such as the camera and processing unit.

[7] The National Union of Rail, Maritime and Transport Workers, Associated Society of Locomotive Engineers and Firemen, and Transport Salaried Staffs' Association, respectively.

It is also important to communicate with the users about any health concerns or uncomfortable feelings that they might encounter with sensors that use infrared technology for facial feature extraction.

3.8 Software Development and Data Analysis

3.8.1 General

A software processor uses various computer vision techniques to process images captured from the sensor to identify drivers' behavioural events that indicate drowsiness and distraction.

Some technologies, such as Convolutional Neural Networks (Masood et al. 2018), show nearly perfect accuracy in distraction recognition, and identification of the cause of careless road driving, especially on use of mobile telephones.

Other machine learning approaches have been implemented in recognising driver fatigue and distraction, and used in manoeuvre detection, and identification of driving behaviour and performance (Meiring and Myburgh 2015).

The Sensitivity and Specificity requirements of the proposed operating concept will be described in Section 5.3 of this paper.

3.8.2 Limitations

Occasional inaccurate outputs generated from software predictions are expected in the early stages of development. False-positive occurs when a driver is misunderstood by the model predicting as having a fatigue or distraction event when they have not. The driver could become discontented about the nuisance caused by the frequent alarm despite him maintaining alertness. To prevent the driver from losing confidence in the new system, events have to be verified to "train" the system's accuracy.

False-negative, on the contrary, is an event being missed, possibly because the sensitivity of the system is not good enough.

3.8.3 Validation

Performance of a software model can be evaluated by a number of validation methods to ensure a good quality of prediction algorithm model that is fair, robust, and is able to protect privacy.

Sensitivity analysis can be carried out (RSSB 2019) together with data review, validation testing, stress testing, and independent review to validate the robustness of the algorithms.

3.8.4 Security and Resilience

With the development of modern technologies, concerns are raised over digital resilience and cyber security. Vigilance systems, alongside other railway subsystems, contain user information and are prone to digital threats. In order to maintain high availability, integrity, and confidentiality, the technology system needs to be well managed to allow quick recovery when dealing with unforeseeable situations. Vigilance system, if installed

with a camera, possess privacy information of train drivers and personal data needs to be protected.

The ISO/IEC 27000 series of standards for Information Security Management Systems form the basis of cyber security for organisations across industry. The IEC 62443 series of standards, on security for industrial automation and control systems, sets out requirements on network and information system. Implementation of changes and system architecture are to be reviewed against CENELEC TS50701, on Cyber Security for Railway Applications, to conform with cyber security management system to identify all threats and mitigation measures.

3.9 Regulatory Challenges

The safety management system conforms to regulatory and legislative frameworks. There can be legal obligations for different parties such as supplier, operating and maintaining of the asset, as well as those responsible for regulating and supervising these activities. It is crucial to identify the areas of overlap between these regulations and the "prediction of driver's risks using machine learning" boundary. The railway industry needs to identify the impact of this change to ensure its implementation meets legal obligations and abides by the Common Safety Method on Risk Evaluation and Assessment (CSM-RA) from (EU) No 402/2013.

Before entering the trial period, any change which may affect safety needs to demonstrate that the resultant risk is acceptable (ALARP). An independent Assessor Body has to be appointed to demonstrate its fulfilment with CSM-RA if the change is deemed significant. Technical and Operational Standards needs to be met in accordance with TSIs, national safety rules and other relevant safety requirements, with approval from the Office of Rail Regulation (ORR).

The DSD system Safety Integrity Level (SIL) should be appropriate for the level of risk being controlled. The functions developed to the SIL level will require an appropriate safety case. Changes on any of these functions need to follow a formal change management process and CSM-RA for approval by the authorities.

4 Method

The vigilance system requires optimisation and extension of its original capability. The current vigilance operation can be tricked, isolated, or become a routine gesture. There is a delay time of 60-second with 5-second action time for the driver to reset the "lack of activity" trigger, which is far too long for trains operating at a typical UK line speeds of 125mph.

The aim of this paper is to improve the capability of the current system, rather than replacing with a new one. Therefore, a Capability Systems Engineering approach is used for this system analysis.

Capability Systems Engineering is commonly used in the military industry and fits into the decomposition stage of the V-lifecycle (Kemp and Daw 2014). Unlike products or systems concerned with outputs or performance, capabilities are more focused on delivering outcomes or effects. The benefits can be understood by realisation through people, processes, information, and equipment. The respective four principles are shown in Figure 3, which is derived INCOSE UK guidance (Kemp and Daw 2014):

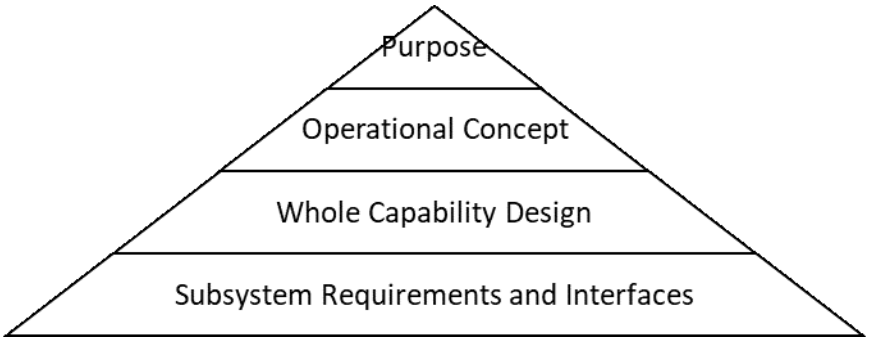


Figure 3 ~ Four Stages of Capability Systems Engineering

The first stage is to establish a clear single statement of purpose and define the scope. Through identification of stakeholders, the client's needs are understood and can help develop the MoEs. These high-level requirements elicited in the MoEs matrices serve as the output of the foundation of future driver monitoring system design process.

Then an Operational Concept is developed to describe the answers to what, why, how, where, when, and who of the new capability.

Figure 4 on the next page (based on INCOSE UK guidance (Kemp and Daw 2014)) shows the process flow of the method used for this paper.

With the aid of Model Based Systems Engineering technique, Use Cases and Activity Diagrams are produced to aid understanding using software tools such as Visio and Enterprise Architect. An example Use Case is presented in Figure 5 overleaf.

In the Whole Capability Design stage, the requirements are verified to ensure that they are captured as required. Preliminary subsystem requirements and interfaces are then developed and linked back to the MoEs for traceability.

5 Assessment / Analysis

5.1 Purpose

The purpose is to improve the capability of the driver's vigilance system on UK mainline railway. Capabilities of how the vigilance system can detect driver's distraction and fatigue, via physiological or cognition state, and actuate accordingly to prevent undesirable events from occurring is being explored.

5.2 Identification of Stakeholders

The purpose of enhancing the Driver's Vigilance System is ultimately to improve the safety of railway passengers. The travelling public are stakeholders that the railway aims to satisfy.

The primary users of the system are train drivers, as employees of the TOCs in UK mainline railway. The initiative can be driven by regulatory bodies such as RSSB, who define the set of system requirements. The drivers are the end user and are the main stakeholder who needs to be kept satisfied.

The secondary users are staff based in the control centres to which the system reports. They receive real-time intervention messages, and regular event summary reports.

The tertiary users include project engineers, who design and implement the system according to requirements, maintain the system to ensure availability, and support in-service system updates.

The TOCs, who are the proposer of the change, need to satisfy the train drivers and their trade unions. The TOCs need to ensure that the system manufactured and installed by the Supplier meets all the requirements, and ensure compliance is met such that approval from the regulator, ORR, can be gained. This requires communication and balance between the interests of the different parties.

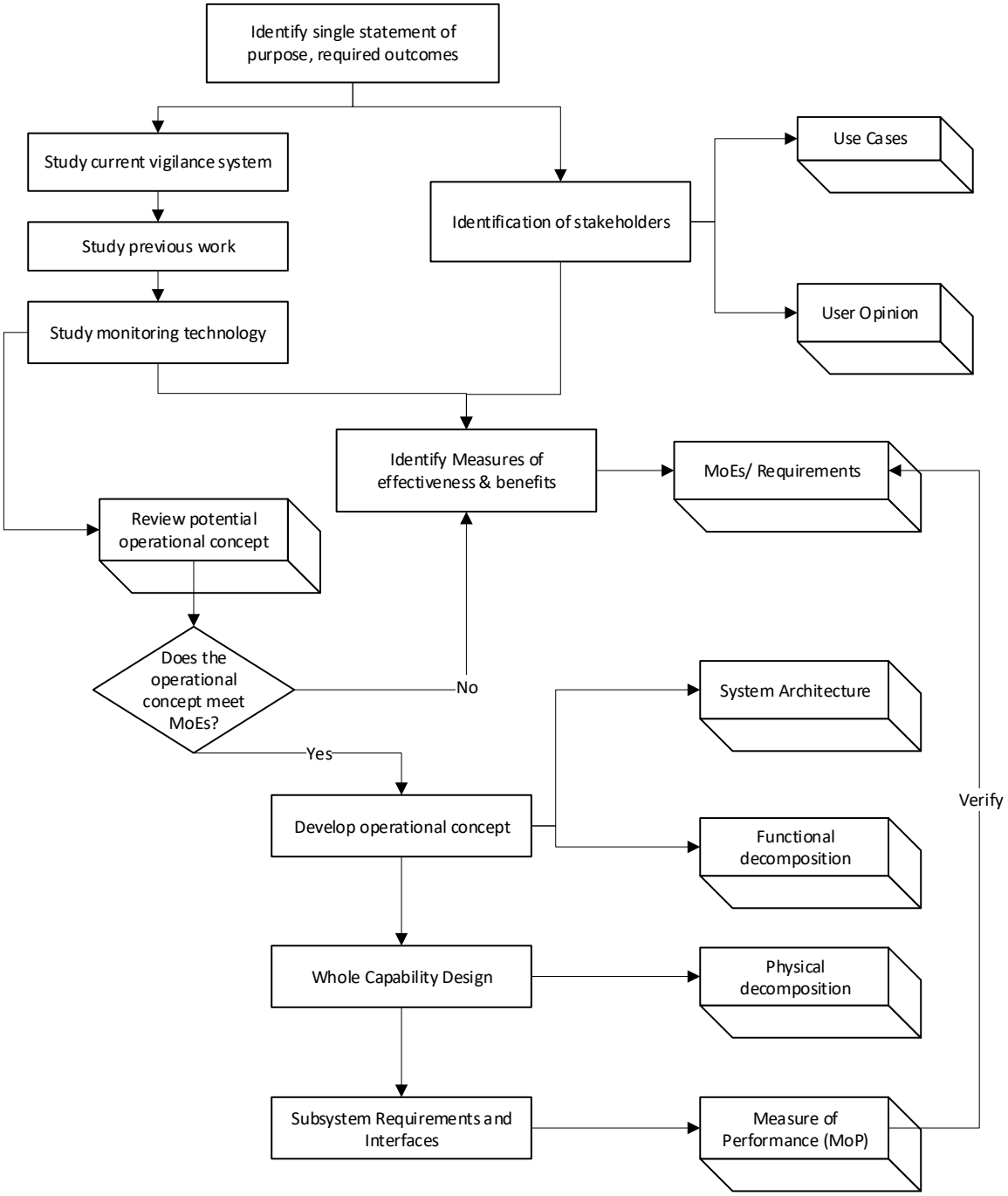


Figure 4 ~ System Review using Capability Systems Engineering Approach

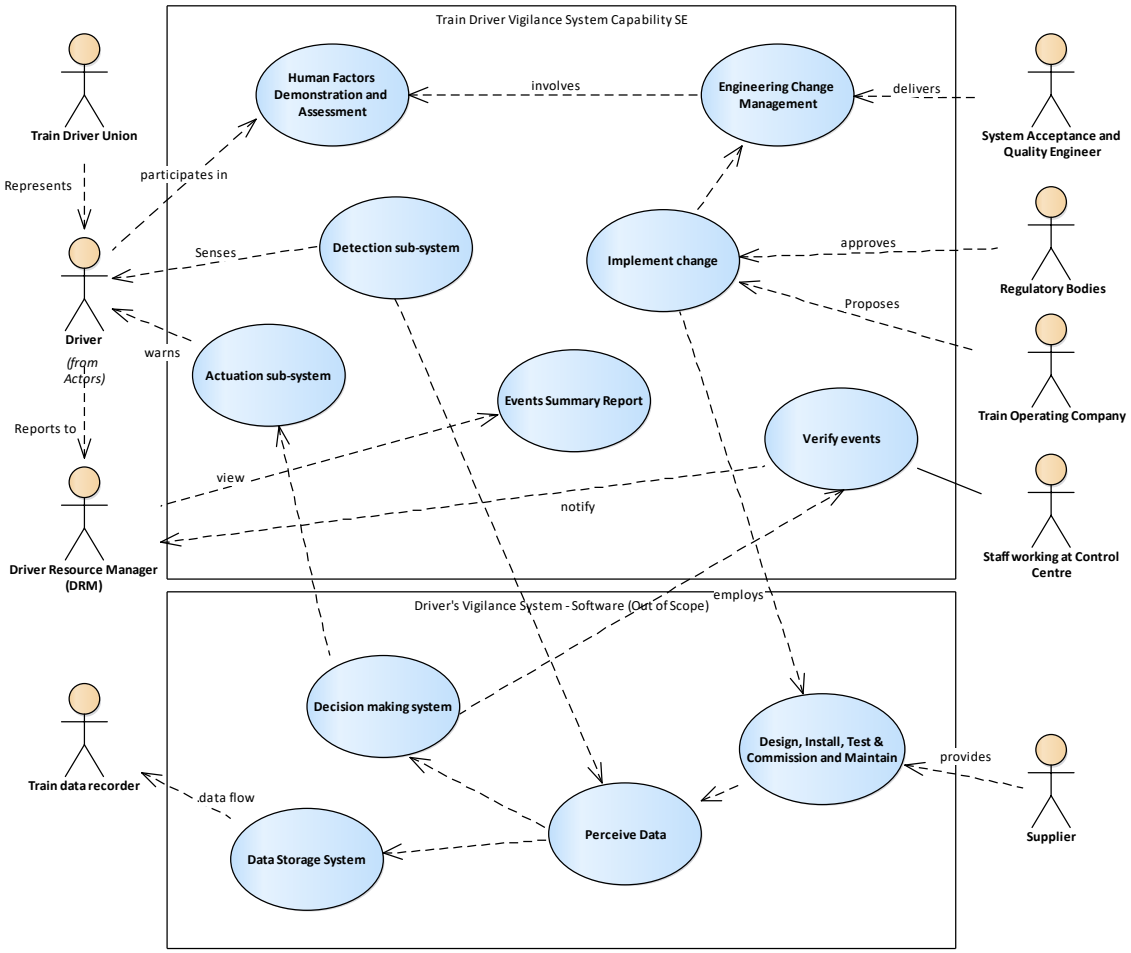


Figure 5 ~ Use Cases Diagram of Driver's Vigilance System

5.3 Measures of Effectiveness

5.3.1 Usability MoEs

MoEs set out the high-level requirements of the system at the operational concept level. The primary users', i.e. the drivers', concerns are collated in the following list of usability MoEs (Table 2). Please note that these high-level requirements are some MoEs suggested by this analysis; further analysis will be required to develop a complete set of the requirements.

The source of reference whence the requirements are derived are recorded in the Traceability column. Some requirements have been taken from, for example, light-rail or automotive applications, and therefore need to be adjusted to the mainline operational environment when being adapted to the system under discussion.

Table 2 ~ High-level Requirements (MoEs) on Usability

No.	Usability Measure of Effectiveness (MoE)	Traceability
Primary User MoEs		
1. U1	Must accommodate the driver to carry out all operation tasks and associated movements. These devices shall provide constant vigilance without any action from the driver. They can be video-based, vehicle based or physiological signals sensors.	Based on Sub-section 3.5 of this paper, and Usability Criteria set out in RSSB research (Whitlock 2002)
2. U2	Interface between the sensing device and the driver must be physically remote to each other such that there is no adverse impact on driver's health and safety due to the device.	Based on section 3.6 of this paper, and Usability Criteria set out in RSSB research (Whitlock 2002)
3. U3	Must accommodate religious head-dresses (e.g. Sikhs' turbans).	Usability Criteria set out in RSSB research (Whitlock 2002)
4. U4	The area of visibility of eye tracking device shall be able to cover a range of driver's height based on an eye level of between 740mm to 855mm above the seat level.	BS EN 14033-1:2007, Clause 14.6 Area of visibility
5. U4	The field of vision and depth of field must accommodate body sizes that range from 5% female to 95% male.	Requirements of camera (von Jan et al. 2010)
6. U5	Any other adjustable features necessary for driving the train under normal conditions shall be positioned: a) With the seat back in an upright position. b) With the seat facing forward and adjusted vertically and longitudinally to place a 50th percentile male in an appropriate driving position for a person of that size.	Railway group standard GM/RT/2100 Clause F.2.5 & F.2.6
7.	Infrared sensor shall emit light below the threshold for human eye safety level, i.e. near infrared (NIR) of wavelength 780 nm.	IR emitted shall be less than the human eye safety threshold (Tufuor 2017). To minimise interference from light sources beyond IR light; and to maintain uniform illumination (Ji and Yang 2002)
8. U6	The device shall accommodate sunglasses worn for driving duties that comply with the relevant requirements of BS EN ISO 12312-1:2013.	Eye and face protection - Sunglasses and related eyewear for general use BS EN ISO 12312-1:2013

No.	Usability Measure of Effectiveness (MoE)	Traceability
Primary User MoEs		
9.	The device shall accommodate corrective spectacles that are in line with Railway Group standard on Train Drivers — Suitability and Medical Fitness Requirements.	Rail Industry Standard RIS-3451-TOM: 2016
10. U7	Calibration shall be within 5 minutes.	Usability Criteria set out in RSSB research (Whitlock 2002)
11. U8	The device shall have a react and reset mechanism.	Based on BS EN 14033-1 Clause 14.11 for current system
12. U12	Need to accommodate different skin colours, and eye and face make-up.	Transport for London (TfL) reported make-up of female drivers have passed trial (Booth 2017)

5.3.2 Functional Requirements

Functional requirements are initially specified at high level, as the capability design is established in detail in later stages. Most importantly, the system shall be able to detect distraction and fatigue of drivers, be able to perceive images, alert on occurrence of events, and notify them accordingly when such events are identified.

Table 3 ~ Functional Requirements of Driver's Vigilance System

No.	Measure of Effectiveness (MoE) / High-level requirements	Traceability
13.	The device shall be able to detect fatigue. Signs include extended eye closure of more than 1.5 seconds.	Eye detection on Microsleep (Poudel et al. 2014)
14.	The device shall be able to detect visual distraction, i.e. eyes off the road of more than 1.8 seconds.	Real-Time Detection of Driver Distraction (Tango and Botta 2013)
15.	The system shall be notified if the driver is absent, that is, out of detection zone for more than 1 second.	Guardian device (Seeing Machines 2019)
16.	The system should be able to measure train speed and acceleration.	Guardian device (Seeing Machines 2019)
17.	The system shall provide a warning to the driver when a distraction event or a fatigue event is detected.	Guardian device (Seeing Machines 2019)
18.	Human machine interface shall provide a function for verifying fatigue events.	To distinguish false-positives manually as part of intervention plan

5.3.3 Non-Functional Requirements

Non-functional requirements (NFRs) are developed based on Performance, Scalability, Availability, Feasibility, Flexibility, Regulation, Operability, and Security, as suggested by the Enterprise Architecture Framework (Deighton 2014) developed from TOGAF, The Open Group Architecture Framework. Cost and commercial aspects are not considered in this study and thus Feasibility is not included in the development of these NFRs.

Table 4 ~ Non-functional Requirements of Driver Vigilance System

No.	Measure of Effectiveness (MoE) / High-level requirements	Traceability
Performance MoE		
19.	The device shall be tested under train driving tasks through: • Train simulator; and • Trial operation.	Scientific Criteria 1, RSSB research on driver vigilance devices (Whitlock 2002)
20.	Detection method shall be validated against recognised measurement methods. Eye blinking rate detection to be validated by the following defined as a fatigue event: • percentage of eye closure over time increases to over 30%, excluding the time spent on normal closure; and • eye closure speed increase to above 0.5s.	Drowsiness detection method (Dinges 1998); and eyelid movement monitoring (Ji and Yang 2002)
21.	Detection method shall be validated against recognised measurement methods. 'Eyes-off-road' to be validated by timing 1.8s defined as a distracted event.	Driver distraction definition (Tango and Botta 2013) is 1.8s for road vehicle. This is assumed to be the same for train driving.
22.	Events data shall be stored locally on the device in the driving cab for at least 24 hours for review.	New data overwrites old data after 24 hours (Seeing Machines 2019)
23.	Sensitivity – The device shall be able to quantify the times it misses an event. • Sensitivity = 100% × hits / (hits + misses) (False-negative) Data regarding the percentage of missed events shall be higher than 90%.	Prototype delivers satisfactory sensitivity of above 90% calculated on a minute basis (von Jan et al. 2010).

No.	Measure of Effectiveness (MoE) / High-level requirements	Traceability
24.	Specificity – The device shall be able to calculate the number of times that it presents a false alarm. • Specificity = 100% × correct rejection / (correct rejection + false alarms) (False-positive) Data regarding the percentage of false alarms shall be higher than 90%.	Prototype delivers satisfactory specificity of above 90% calculated on a minute basis (von Jan et al. 2010).
25.	Reaction time shall be short enough, i.e. less than 2.5s, to provide real-time feedback to alarm the driver.	Train at 125mph travels 139m in 2.5 seconds. Reaction time requirement for acknowledgement of TPWS horn is 2.5 seconds (El Rashidy et al. 2016)
Scalability MoEs		
26.	The ability of the backend system to handle increasing or decreasing volumes of services and data of up to 500 driving cabs or trains.	14,025 current operating trains in UK (RSSSG 2018) divided by 28 TOCs which equals an average of 500 trains per TOC
Availability MoE		
27.	Reliability study considering the failure mode of components and the failure rate of the function shall be provided. Mean Time between Failure (MTBF) of Driver Vigilance System shall be at least 100,000 hours.	Reliability to be re-assessed based on changes in overall system architecture and new components. Failure of monitoring system is service affecting. Based on (EU) No 1302/2014 requirement for reliability study and EKE-Electronics Ltd (2017) MTBF figure, see Appendix A
28.	Mean Time to Repair (MTTR) of Driver Vigilance System shall be within 1 hour.	Active repair time excluding logistics and testing
29.	The control centre shall be notified when signal from the train cab is lost for more than 30s seconds.	Half the time of 60s detection for lack of driver's activity as defined in BS EN14033-1 Clause 14.11

No.	Measure of Effectiveness (MoE) / High-level requirements	Traceability
Flexibility MoE		
30.	The backend system shall possess an interface to allow change and extension of functionality including: • Set up equipment for a new train; and • Change intervention plan.	Staff are able to sustain and manage the system on a daily basis
Regulation MoEs		
31.	Meet UK standards in accordance with EN50126 on RAMS, EN50716 on Software and EN50129 on hardware, or equivalent.	European Standards EN50126, EN50716 and EN50129
32.	Shock/vibration compliance according to EN61373 Rolling stock equipment — Shock and vibration tests.	European Standard EN 61373
33.	The Driver's safety device (DSD) that operates by stopping trains if driver become incapacitated must meet the appropriate SIL.	Manufacturer datasheet as an example where the existing DSD meets SIL 3: Safe-plus module instruction handbook (DEUTA-WERKE 2019)
34.	The design should allow deactivation of the DSD function in case of equipment failure, e.g. when the DSD does not reset.	Railway Group Standard on monitoring device (RSSB 2021)
35.	Meet UK Safety regulation Common Safety Method for Risk Evaluation and Assessment (CSM-RA).	Implementing Regulation (EU) No 402/2013
36.	Meet UK EMC requirement: EN 50121-3-2:2016 for Rolling stock apparatus. • The device should be robust against magnetic (or otherwise) interference from traction motors, overhead power cables and the electrified third rail; and • If the device uses telemetry for transferring data, interference of data transfer between current and future train-to-track wireless communications shall be within standard requirements.	EN Standard 50121-3-2:2016, and UK Railway Context Criteria (Whitlock 2002)
37.	The device shall be compliant with GM/RT/2000 Engineering Acceptance of Rail Vehicles.	Railway Group Standard GM/RT/2000

No.	Measure of Effectiveness (MoE) / High-level requirements	Traceability
Operability MoEs		
38.	The device shall have the facility to connection to other train interface components, if required, e.g. • Traction Brake Controller (TBC); • AWS; and • OTMR.	Edited based on UK Railway Context Criteria (Whitlock 2002)
39.	To record and store verified events for up to 12 months for retrieval.	Footage of the event are available to view for up to 1 year (Seeing Machines 2019)
40.	Eye tracking devices shall 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.	UK Railway Context Criteria (Whitlock 2002)
41.	The device shall be able to operate in both air-conditioned and non-air conditioned environments, i.e. an airflow of at least 30 m^3 per hour per person.	EN14033-1: 2007 Clause 14.4 Heating, cooling and ventilation
42.	The device must: (a) Tolerate a temperature range between -20℃ to +50℃ inside the vehicle when non-operational; and (b) Tolerate a range of 18℃ to 23℃ in the cab when operational.	EN50125-1:2014; and Thermal load of the new system shall be managed such that it has sufficient hardware capacity and a cooling mechanism to prevent overheating. EN14033-1: 2007 Clause 14.4 Heating, cooling and ventilation
43.	The device shall be able to operate under typical light condition of a driving cab which is between 30lx to 60lx of internal lighting.	EN14033-1: 2007 Clause 14.5 Internal Lighting
44.	The device manufacturer shall provide an operating manual that details 1. System description; 2. Operational instructions; and 3. Maintenance procedure.	Engineering Experience on Rolling Stock project
45.	Drivers have sufficient training to be familiar with the change in system in accordance with train driver mental workload guidance note.	Driver mental workload (RSSB 2005b)

No.	Measure of Effectiveness (MoE) / High-level requirements	Traceability
Cyber Security MoEs		
46.	The system shall protect information confidentiality and integrity. • Normal driving video footage shall be kept in memory for processing purpose only, i.e. no data storage or retention; and • Driver identity including name and staff ID shall only be available upon request from DRM.	Ethical concerns referenced from Guardian Device (Seeing Machines 2019) Confidentiality and Integrity Algorithms for UMTS and LTE (ETSI 2018)
47.	Wireless communication must be encrypted using secured network, such as 4G LTE. Additionally, the system shall be designed for data to be encrypted before transmission.	InfoSec

5.4 Operational Concept

The existing system is proposed to be re-designed with enhanced capability to monitor drivers' fatigue and distraction events and give alert accordingly, as illustrated in Figure 6.

Symptoms of distraction and fatigue events can both be captured using image processing technique by analysis driver's eye and head movements. The benefits of camera sensors outweigh all other kinds of technologies in that it is easier to use, less invasive, and more accurate. Video-based sensors can thus be used for capturing images of the driver.

Figure 6 shows that visual distraction is detected when the driver looks away for more than 1.8s; this actuates an audio alarm. This is within the reaction time requirement for driver's performance of 2.5s on acknowledging a train protection equipment button. To reset the system, the driver looks back at the centre, and the ringing sound is turned off.

A fatigue event is defined as the drivers' percentage of eye closure over time increasing to above 30%, excluding the time spent on normal closure (Dinges 1998), and eye closure speed increases to more than 0.5s (Ji and Yang, 2002). This actuates the vibration alarm at the driver's seat, as well as the audio alarm. A vibration alarm is used for fatigued drivers because people who experiences microsleep do not react to light or sound (Created Mode 2020). Once the driver reopens his or her eyes, the system is reset, and the alarm goes off.

The delay time of reacting to a fatigue event and warning being reset is thus reduced from 5 seconds to 2 seconds. The improved system allows detection of drivers who softly close eyes who can still react to sound. There is thus constant vigilance that actuates in real-time without interfering with driver's operations. The 2 seconds estimate is based on 1.8s for visual distraction plus digital transmission time.

The delay time for drivers who merely softly close their eyes and can be returned to being attentive by audio beeping is reduced from 30s (*5s initiation + 20s detection + 5s after alarm flashes*) to 2s. The reset time is typically 5 to 7 seconds and the shortest time is used for worst case analysis.

For drivers who are asleep and cannot be woken up by audio beeping, but can be woken up by seat vibration, the delay time is reduced from 65s (*5s initiation + 60s delay time*) to 2s.

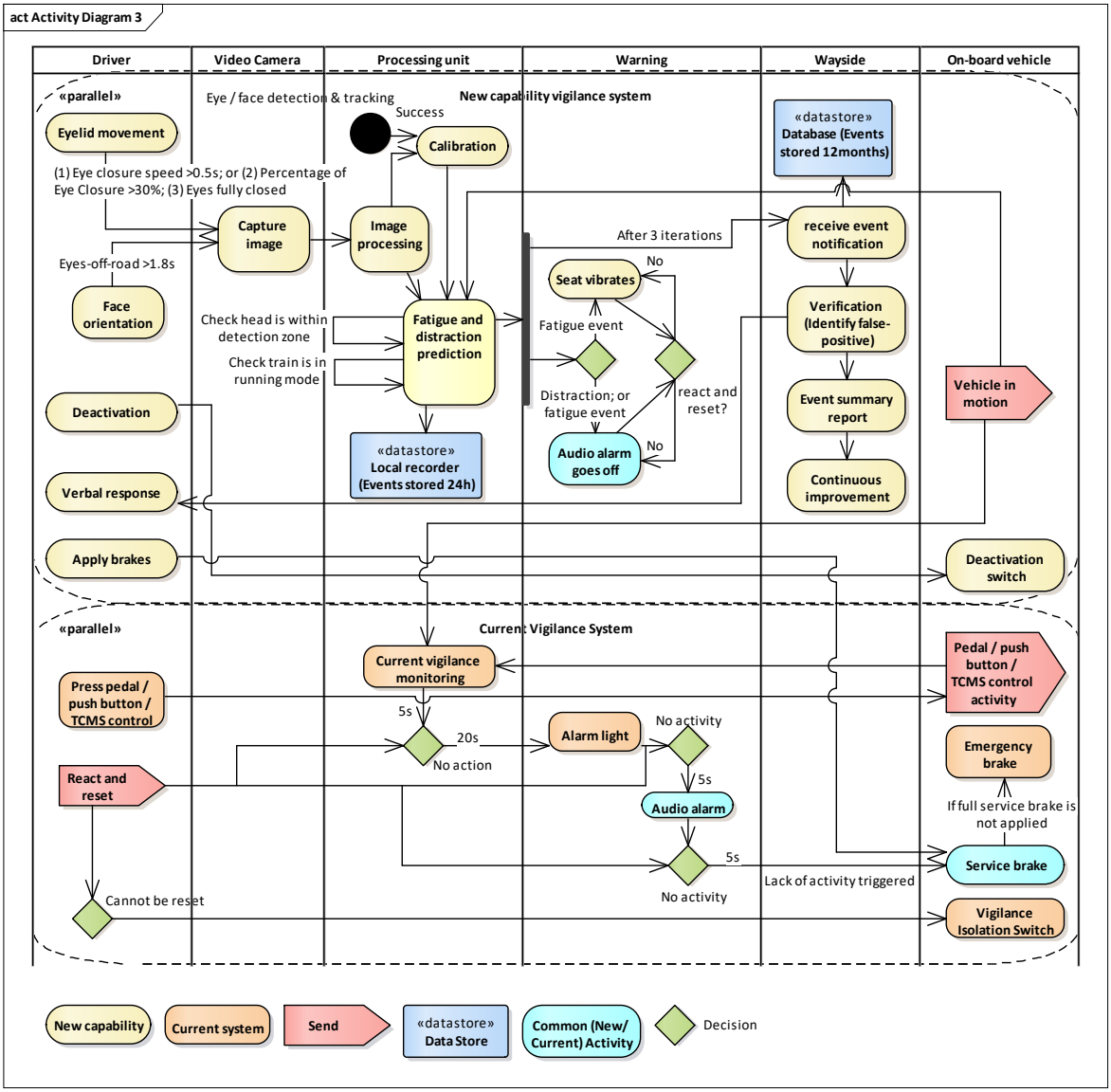


Figure 6 ~ Operational Concept of the New Capability

The proposed new capability of the vigilance system serves as a redundancy system to the existing DVD to monitor whether the driver has lost consciousness. In Figure 6, the new capability to detect driver's alertness by signs of distraction and fatigue is denoted in yellow. The existing vigilance system is denoted in blue, which forms the baseline of the discussion.

If consecutive fatigue events are detected, wireless messages are transmitted to the control centre to notify the staff of a fatigue event. It is determined mutually between the driver and the control centre staff to stop the train, or to be decided by the staff unilaterally to apply brakes if no reaction is received from the driver.

For drivers who are extremely tired, and would like to take a break, the response time is 129s [*3 iterations × (2s event triggered × 1s actuator reacts) + 60s verification + 60s contact DRM*]. The number of 3 iterations are based on the Guardian Device in which two fatigue events are allowed before notifying the supervisor, however, this can be negotiated to suit each TOC's management policy if required.

The reaction time for drivers who become incapacitated or dead remain the same at 65s because only the current DSD is connected to the emergency brakes, and can automatically stop the train without any delay in verifying or communicating with the DRM.

The drivers are able to deactivate and isolate the equipment when it fails to reset. The driver can continue train operation until completion of train journey where the failed device would be repaired, or replaced at the depot.

Distraction and fatigue events are summarised in a regular event summary report for fatigue management as part of the operator's continual improvement programme.

5.5 Whole Capability Design

5.5.1 Physical Decomposition

The proposed system with improved functionality is able to track fatigue, unintentional and intentional distraction, such as playing video games on smartphones, reading newspaper, or microsleep events.

The physical decomposition of the new capability can be structured into three parts. They are the driver's cab subsystem, the vehicle on-board subsystem, and the wayside subsystem, see Figure 7.

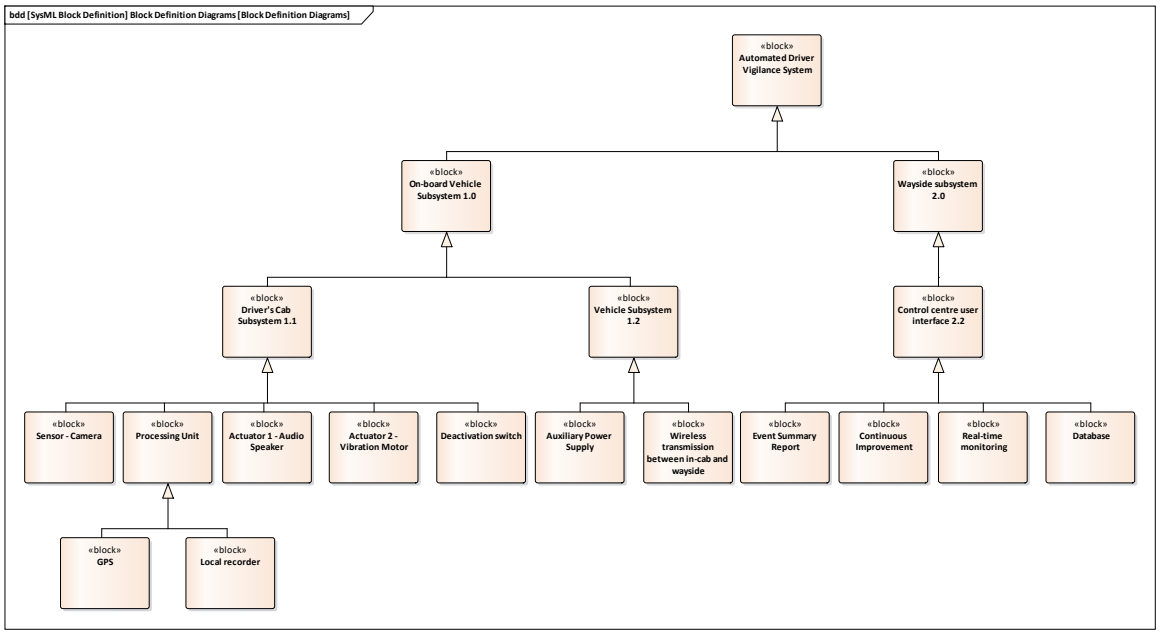


Figure 7 ~ Physical Decomposition of the New Capability

5.5.2 Driver's Cab

This subsystem consists of components installed in the driver's cab.

A sensing device is used to record images of the driver's head. Once initiated, it calibrates each individual's features when using the device for the first time. The sensing subsystem is made up of a sensing device, a controller, and a power module (Toto 2012), all installed inside the cab.

The system uses an infrared (IR) illuminator which serve various purposes. It eliminates the impact of the variable light conditions during driving; day or night or inside tunnels. IR detects bright pupil effects even with sunglasses on (Ji and Yang 2002).

Near-infrared (NIR) is barely visible to the driver, minimising interference to their daily operation. As long as the wavelength is set at 780nm or more, the beam is invisible to human eye, does not cause damage to human when exposed for long periods of time, and is considered safe (Tufuor 2017).

A driver-facing video camera with an NIR illuminator can thus be fitted in the driving cab to serve these functions while satisfying MoEs 44, 8 and 7 respectively.

The software part of the Vigilance System carries out biometric analysis. Data collected are sent to the processing unit for extraction, transformation, and information classification. The processing unit has a GPS[8] sensor, which measures train speed and acceleration. Normal video footage of driver shall be overwritten after 24 hours inside the driving cab storage unit, as defined in MoE 22.

The audio speaker is used for giving hearable alarms to the driver. Any modifications to the audio speaker should aim at minimal disturbance to existing systems, such that impact to other safety-critical systems can be avoided. The vibration alarm is provided by a dedicated motor located inside the driver's seat.

To allow isolation of the equipment if it fails, a breaker switch is installed in the driving cab for the driver to deactivate the system when required.

5.5.3 On-board Vehicle

The equipment on-board the vehicle needs a low voltage power supply from the vehicle, which comes from the Auxiliary Power Supply, part of the vehicle's traction system.

Wireless transmission equipment is fitted to allow signals to be communicated between on-board vehicle systems and the wayside. To demonstrate that the vehicle system is live, a signal is sent to the wayside every 5s. The system receives a signal lost notification when the train passes through a tunnel, or an area with poor network, as required in MoE 29. A few seconds queuing delay is allowed for the signal to be detected once network is resumed.

The current system architecture of the DSD with connection to the Service and Emergency brake can be maintained with no modifications required for the new capability. This is to minimise safety impact on critical systems.

The device shall obtain inputs from a speedometer from the TCMS to determine whether the train is in running mode, and in motion.

To summarise, subsystems on-board train are comprised of the Auxiliary Power Supply, Processing Unit (with GPS sensor), Wireless communication, and connection with a speed indicator.

[8] Global Positioning System

5.5.4 Wayside

An interface is needed for the monitoring team to be notified about fatigue events. The design of the user interface shall allow staff to classify events into either false-positive or confirm as actual fatigue events.

Records of fatigue events are stored for up to 12 months for analysis purposes, as required in MoE 40. Frequency of events' occurrence can be compared between different work shift patterns to inform the fatigue management programme.

The user interface for control centre staff thus needs to possess three main functions: Real Time Monitoring, Event Summary Reporting, and a Continual Improvement Programme. The DRM can use analysis results for fatigue management and analysis in the longer term.

5.6 Subsystem Requirements

Physical subsystems are assessed through a set of Measures of Performance (MoPs) which list out the minimum threshold for subsystem requirements. Traceability is provided to justify how they relate to higher level performance requirements (i.e. the MoEs). Please note that these requirements are examples suggested by this analysis for demonstration purposes. Further analysis is required to develop a complete set of the requirements.

Table 5 ~ Subsystem Measures of Performance (MoPs)

Domain	Requirement	Threshold	Justification
Video sensor (camera)	Camera resolution is higher than…	720 x 576 pixels with refresh rate of 12 frames per second.	Images are clear enough for evaluation. Rail Industry Standard RIS-2703-RST Driver Controlled Operation (DCO) On-Train Camera/Monitors (OTCM); and Driver Monitoring Systems (DMS) and Occupant Monitoring Systems (NXP 2020)
Video sensor (camera)	Camera field of view (FOV)	60 degree	Cover head position for a range of user's height. Driver Monitoring Systems (DMS) and Occupant Monitoring Systems (NXP 2020); and Rail Industry Standard RIS-2703-RST Driver Controlled Operation (DCO) On-Train Camera/Monitors (OTCM)
Video sensor (camera)	Calibration time shall be less than	5 minutes	To be completed alongside Start of Mission (SoM) of the vehicle. RSSB usability criteria (Whitlock 2002)
Video sensor (camera)	Monitor condition every…	2 seconds	Heart rate detection by Steer wearable device (Created Mode 2020)
Video sensor (camera)	Noise emitted during operation is lower than	1dBa	Video fatigue and distraction monitoring (Progress Rail 2015)

Domain	Requirement	Threshold	Justification
Video sensor (camera)	Narrow bandpass NIR filter shall be attached to the front of the lens to attenuate light below…	780 nm	To minimise interference from light sources beyond IR light; and to maintain uniform illumination (Ji and Yang 2002). IR with wavelength 780nm is invisible to human eye and is below the threshold for human eye safety (Tufuor 2017).
Vibration motor	Vibration rate must be higher than	15Hz	Low frequency vibration corelates to poor driving performance and drowsiness (Azizan and Ittianuwat 2016).
Audio alarm	Alarm sound shall be at least … higher than noise level in the driving cab	6dBa	Acoustic warning devices requirements in (EU) No 1302/2014
Monitoring System	Reaction time is less than	1s	Short enough to provide real-time feedback to alarm the driver.
Processing unit	Support transmission speed of at least	5Mbps	720p streaming of high-definition video require a bandwidth of at least 5Mbps (Zen 2019)
Real-time intervention	Response time for verification is less than…	1 minute	Short enough to verify fatigue event and obtain mutual agreement on intervention action. Video fatigue and distraction monitoring (Progress Rail 2015)
Human-machine interface	Event summary report is available every …	1 week	Align with Video fatigue and distraction monitoring (Progress Rail 2015)

MoPs of hardware and frontend subsystems that directly interface with the users are set out with justification. Image processing software and prediction algorithms used to identify parameters and to calculate drivers' fitness level are not discussed in detailed. It is proposed that future work be done by a psychology, or physiology, expert with software engineering background.

5.7 Interface and Safety Impact

Technical interfaces of the subsystems are traded out to understand the relationship between contributing elements.

It is not recommended that the new capability be integrated with the existing braking system and DSD at this stage. The consequences of failure of these safety critical systems could be catastrophic. Minimising modifications on the current systems allows the DSD to continue to operate if the new DVD fails. An ALARP argument will be required at option selection stage on whether the risk is acceptably controlled for the improved capability of the DSD to not interface with the existing systems.

Any changes in the vehicle needs to comply with the CSM-RA. Although novel, the likelihood of the change being significant is lower if implemented without integrating, but if it were integrated with the current system, it would interface with safety critical systems (the current braking system and DSD). A Quantitative Risk Assessment needs to be carried out to meet SIL allocation targets.

One of the foreseeable interface hazards is interference with the existing communication system to the signaller. Wireless transmission is used for sending event notification to wayside and checking of signals. It is essential to ensure that it does not interfere with the existing wireless transmission of the train control management system. This can be validated by conducting EMC tests in compliance with the BS EN 50121 series of standards on railway electromagnetic compatibility.

For systems that involve operational technology, security-informed safety needs to be addressed. Security hazards include leakage of confidential personal information through cyber incidents, such as hacking. This may have a detrimental effect on the company's reputation. The system architecture has to be robustly built according to the IEC 62443 series of standards regarding security for industrial automation and control systems. Both 'data at rest' and 'data in motion' need to be encrypted as part of maintaining cyber security and recovery throughout the whole life cycle.

To ensure distraction and confusion to drivers are minimised, the new DVD has to be designed ergonomically. Causes of distraction might be unfamiliar alarms and warnings (both audio and visible); discomfort from vibrating seats; and perception of the infrared beam. These can potentially lead to a driver being unaware of a critical alarm and taking inappropriate action. Sufficient driver training, human factors assessment, and trial exercises shall be conducted to collect user feedback and to ensure warnings are given clearly. As explained in MoE 7, the infrared beam wavelength has to be set in the NIR range above the safety threshold at 780nm.

To satisfy MoE 1, it is critical to ensure operation of the new system does not interfere with driving operations. A specific concern is the frequency and timing of when the old and new audio alarms would go off; it is shown in Figure 8 that for the new system, the audio alarm occurs within the first 15s, whereas for the current system, the buzzer sound becomes active after 30s of driver inactivity. Therefore, no overlap of audio alarms is foreseen that could cause driver confusion.

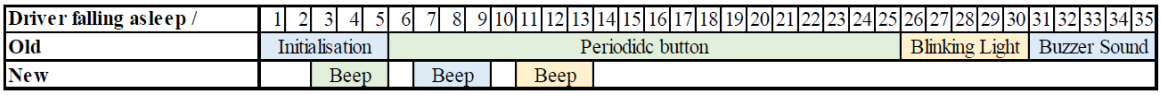


Figure 8 ~ Comparison of Frequency of Audio Alarm between Current and New Vigilance System

The users need to be assured that the system design meets their needs, and that this system is not intended for surveillance purposes by their managers. An acknowledgement button shall be available for the driver to reset the warning. Implementation should be voluntary, such that a deactivation switch shall be available for drivers to isolate the system, although this switch is intended for isolation of the device when it fails. The drivers should also be able to cancel the notification to the control centre. A driver's identity is only available upon request and is not shown on human-machine interface summary reports. Distraction events are not used for real-time intervention. Video footage stored locally is to be overwritten after 24 hours.

6 Discussion of Results

6.1 Results

The current DSD is to remain as it is still important for detecting drivers who become incapacitated or dead. It would also serve as a backstop if the new vigilance system were to fail. The new vigilance system is most effective for drivers asleep who cannot be woken up by audio alarms. Driver who experience microsleep can be woken by vibration, but not by the beeping sound. In such cases, the reaction time drop from 65s to 2s resulting in a 97% decrease. Table 6 below shows the extent of improved capability in the column 'Percentage of Reduction'.

Table 6 ~ Comparison Between Current and New Vigilance Systems on the Delay Time Between the Onset of Inattention and the Warning Being Reset

Level of Driver Readiness	**Reaction Time**		
	Current Vigilance System	**New Vigilance System**	**Percentage of Reduction**
Driver incapacitated/dead	65s	65s	No Change
Driver asleep but *cannot* be woken up by beeping sound	65s	2s	97%
Driver asleep but *can* be woken up by beeping sound	30s	2s	93%
Microsleep or driver who softly closes eyes	N/A	2s	N/A
Distracted driver (both intentional and unintentional)	N/A	2-3s	N/A
Drivers who experience Highway Hypnosis	N/A	N/A	N/A

New functionalities include detection of microsleep and distraction. Neither system is yet capable of detecting highway hypnosis.

6.2 Application

Vigilance monitoring is widely adopted in freight vehicles in USA and Australia (Seeing Machines 2019), and has now been transformed to be used for light rail drivers (RAIB 2019). The proposed system would provide enhancement of capability for current DSD and associated DVD for all TOCs and manufacturers in UK mainline railway who conform with EN standards. RSSB has recently published research (RSSB 2021) on understanding the functional requirements for train driver alertness and attention monitoring devices. The study went on to discuss the devices that have been chosen to be used in the railway industry, usually involving only one or two specific suppliers. This approach lacks a comprehensive analysis, considering all possible solutions, and has not identified measurable requirements that can be verified. However, it reflects the criticality and urgent need to improve the capability of existing vigilance device for national use.

If implemented successfully, this system is foreseen to reduce 20.7% of overall fatal train accidents in UK. This figure is calculated based on multiplying 44% of accidents caused

by SPAD or over-speeding (Evans 2017), and 49% of these accidents caused by the driver's alertness and distraction (RSSB 2021) with an additional 4% involving the driver's incapacitated or asleep, where:

- *44% × (49% - 5% + 3%) = 20.68%*;
- assuming 1% are from incapacitated drivers and 3% are from asleep drivers, out of the 4% of drivers being incapacitated or asleep; and
- assuming the software algorithm is 100% effective; and
- assuming the system is used on every journey; and
- excluding accidents caused by drivers experiencing highway hypnosis, which is assumed to be 5%. (Further analysis is required to understand the breakdown of accident causes to obtain a more accurate figure.)

Apart from passenger vehicles, this new capability can be explored for UK rail freight usage as well.

6.3 Limitations

There are caveats on the new capability regarding the validity of road data that need verifying for the rail environment. Most research and data found for fatigue, distraction and inertia detection are based on road driving. Working nature and shifts are however different from railway environment; controls and road regulations are more complex. A separate investigation is needed for the railway to redefine these values specifically.

Related work has been done on determination of fatigue and alertness based on gaze determination by pupil and glint tracking, as well as face orientation monitoring using properties of pupils (Haq and Hasan 2016). The fatigue determination threshold varies, depending on skin colour and colour of the iris (Haq and Hasan 2016). Due to the complexity of this algorithm, these factors are not included in the consideration of this paper.

Prediction algorithms (von Jan et al. 2010), and their on-board implementation falls under the software evaluation process, which has not been studied in detail in this paper. A major concern around Machine Learning technology is its inherent black box nature. Computer vision processing using non-traditional modelling also remains a controversial topic, and requires further development, particularly on how integration with safety-critical systems can be done in railway industry.

6.4 Challenges

Implementing changes to the driver's cab is challenging, because of all the stakeholders that need to be satisfied. The train drivers' union called for strikes relating to Croydon trams being fitted with the infrared sleep sensor. Health concerns such as headaches and blurred vision were claimed to be caused by the new device. Although TfL claimed that the system is safe, with many years' experience of it use in the road haulage industry (BBC 2017), the implementation of change is still yet to be achieved with full operation.

The video camera sensor is associated with facial recognition technology, which is a controversial topic. One wonders if this is a breach of human rights. The usage of the new vigilance system thus shall be rolled out on a voluntary basis. The driver can deactivate the function when wishing to be withdrawn from the programme.

There needs to be a clear agreement that employers shall not use the technology for performance management, or for disciplinary action. The technology should be discussed at length with drivers and their trade union representatives before introduction.

The new capability needs to assure the users of confidentiality of their personal data, as well as the benefits that can be brought to both the individual, the passenger, and the railway as a whole. If employers do the right thing, I believe the trade unions can help them convince the employees; to explain that the introduction of this technology is to make driving safer whilst not compromising their privacy.

6.5 Implementation Opportunities

The first phase of implementation should involve a defect liability period, focusing on the detection and alarm process of distraction and fatigue events within the drivers' cab. Data collected from the events should be analysed, and changes made according to feedback from the primary user as well as the output of the analysis.

Although detection of facial expressions has been under development for years, the application is novel to rail industry. Therefore, a period for identifying defects for specific application to train driving cab should be allowed before full operation.

Once any defects are resolved, the project can move to a second phase which implements the connection with the wayside system.

It is estimated that this system can be rolled out in one year from start of development. This include 2 months of planning, 4 months of design and build, 2 months of installation ,and 4 months of testing and commissioning. It took eight months for the Croydon tram to implement the Guardian device after the fatal accident investigation (Booth 2017), but the regulations and stakeholders are more complex for mainline rail, therefore, it is considered that one year is a reasonable timeframe.

The immediate benefit of the vigilance system is to reduce fatigue and distraction occurrences, and thus improve safety, if implemented successfully. In the longer term, a continual improvement programme can be rolled out to strategically plan work shift rosters and manage fatigue more effectively.

With the popularity of autonomous driving alongside upgrade of Grade of Automation, one may query the value of developing such a device for drivers. Autonomous driving for metros has been under rapid development in recent years.

However, there is actually a low chance of drivers becoming redundant in the near future on the mainline railway. According to Stagecoach Group plc, at the time of the research there were tens of thousands of railway drivers employed to run the UK train network. Compared to metro or light rail, the mainline railway has a slower pace of introducing automation due to its complexity and longer journeys. Even if automation is granted, drivers are still needed to be maintained with continuous driver training for dealing with emergency situations.

7 Conclusions

7.1 Summary

A capability study has been carried out on a drivers' vigilance system to understand the high-level requirements, should UK mainline railways plan to adopt this monitoring system. Throughout the systems engineering process, the functional and non-functional requirements were captured and verified once the whole capability design had been developed. The new vigilance system was found to improve reaction time of fatigue and distraction events detection by more than 90%, and under general assumptions, this would reduce fatal train accidents in UK by up to 20.7% once implemented.

7.2 Findings

It is believed that there is an urgent need for transforming current DSD and DVD system to address its inherent shortcomings. As discussed in Sub-section 2.2, the existing system has a long delay time, can be easily isolated and cannot detect microsleep. The improved capability of the vigilance system is able of detecting microsleep that takes place between 0.5s to 30s, which the traditional device is not able to spot. A significant improvement is shown compared to the current system with delay time of 60s. It is also able to alert the driver of distraction events if they looked away for more than 1.8s. This additional functionality enables the passengers to be "in safe hands", away from a driver's intentional distraction. The system is not intended for detecting a driver becoming incapacitated or dead, which is currently covered in the existing DSD.

The system needs to be designed in a way to deal with a wide range of scenarios. Eye detection technology needs to be sophisticated enough to produce accurate results for populations with a variety of iris colour and skin colour. Other situations include operational aspects when the system is being intentionally tricked, or if the camera is obscured. There should be design consideration and rules in place, in combination with driver training to avoid the occurrence of these behaviours.

Compared to previous research, one of the innovations of my project is the method of adopting the Capability System Engineering approach. This process allows a system-wide overview of the vigilance system tailor-made for UK mainline railway. Unlike other papers that merely compare available gadgets on the market from a supplier's or purchaser's point of view, this system analysis provides a holistic understanding of industrial needs, guided by stakeholders' wishes and requirements.

7.3 Recommendations

Future work involving research and trials on the mainline railway, of drivers fatigue and distraction events in correlation to their physiological status will be helpful to determine detection thresholds, because the available data are mainly from road haulage vehicles, in which the driving pattern and working nature are significantly different.

Further work on this topic can be done extending the scope to cover driver operations in abnormal scenarios, for example in an emergency situation. Software development needs to understand the associated drivers' tasks during these circumstances.

Separate assessment is recommended for future integration with current vigilance device, which involving safety-critical systems. Interfaces with braking control, DSD control, and

the train management system require consideration and a formal change management process.

Fatigue determination using computer vision algorithms has not been discussed in detail in this paper. Future work is recommended to research a comprehensive method for fatigue and distraction prediction, and to modify the software model accordingly. This would best be done by a physiology or psychology expert, ideally with image processing and evaluation experiences. This is an iterative process that relies on technical disciplinary knowledge, and behavioural and medical sciences.

Starting off with a simple version, then eventually migrating to a vigilance system that caters for all scenarios, would be the ideal approach. Over time, the specifications of the product will be refined to determinate the nature of the final vigilance system. The best way would be for RSSB, RDG or DfT to put in place a set of high-level requirements as a standard for the improved capability of the vigilance system, and to fund development of a prototype demonstrator, or even a full system. This will ensure a consistent implementation across the industry.

A Polish physicist[9] once said, "*Nothing in life is to be feared, it is only to be understood*". The intent of the system analysis conducted was to facilitate the decision making of railway undertakings, by identifying the benefits and trade-offs of implementing a driving monitoring system. Only by exploring the requirements that need to be achieved, and addressing concerns associated with all stakeholders can the railway industry continue to strive to be a better and safer transportation mode.

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References

Azizan A. and Ittianuwat R. (2016). *Effect Of Vibration On Occupant Driving Performances: Measured By Simulated Driving*. International Journal of Scientific & Technology Research, Volume 5, Issue 01, January 2016. https://www.ijstr.org/final-print/jan2016/Effect-Of-Vibration-On-Occupant-Driving-Performances-Measured-By-Simulated-Driving.pdf. Accessed 12th July 2024.

BBC. (2017). *Croydon Tram drivers to strike over 'sleep detectors'*. BBC News, 1 November 2017. https://www.bbc.co.uk/news/uk-england-london-41830688. Accessed 12th July 2024.

[9] Maria Skłodowska-Curie (1867 – 1934), also known as Marie Curie.

Booth S. (2017). *We take a look at the controversial new safety device installed on Croydon trams.* Croydon Advertiser, 8th November 2017. https://www.croydonadvertiser.co.uk/news/croydon-news/take-look-controversial-new-safety-742796. Accessed 12th July 2024.

BS EN 13452-1. (2003) *Railway applications. Braking. Mass transit brake systems. Part 1: Performance requirements*. British Standard Institution.

BS EN 14033-1. (2017). *Railway applications. Track. Railbound construction and maintenance machines. Part 1: Technical requirements for running.* British Standards Institution.

BS EN 15734-2. (2010). *Railway applications. Braking systems of high speed trains. Part 2: Test methods*. British Standards Institution.

Commissaris R. (2019). *Unpublished Interview with Randall Commissaris, Ph.D., Professor of Wayne State University* (2 January 2019).

Created Mode. (2020). STEER: Wearable Device That Will Not Let You Fall Asleep. Kickstarter, 28 November 2020.

D'Agostino A. (2016). *Big Data in Railways — Common Occurrence Reporting Programme*. Technical Document ERA-PRG-004-TD-003 V 1.0. European Union Agency for Railways.

Deayea. (2019). *China High Speed Rail Brain Wave Sensor*. Deayea Technology Ltd., Shanghai.

de Castella T. (2015). *InterCity 125 v Hitachi: What are the UK's new trains like?* BBC News, 12 March 2015. https://www.bbc.co.uk/news/magazine-31831603. Accessed 12th July 2024.

Deighton D. (2014). *Enterprise Architecture Framework*. University of Birmingham.

DEUTA-WERKE. (2019). *Safe+ Module Instruction Handbook*. DEUTA-WERKE GmbH

Dinges D. F., Mallis M. M., Maislin G., and Powell J. W. (1998). *Evaluation of Techniques for Ocular Measurement as an Index of Fatigue and the Basis for Alertness Management*. U.S. Department of Transportation, National Highway Traffic Safety Administration Report DOT HS 808 762.

Dorrian J. (2008). *The driver vigilance telemetric control system (DVTCS): Investigating sensitivity to experimentally induced sleep loss and fatigue*. University of South Australia, Adelaide.

Doudou M., Bouabdallah A., and Charfaoui V. (2018). *A Light on Physiological Sensors for Efficient Driver Drowsiness Detection System*. Sensors & Transducers Journal, International Frequency Sensor Association (IFSA), 2018, 224 (8), pp.39-50.

EKE-Electronics Ltd. (2017). *Vigilance Control System (VCS)*. EKE-Electronics Ltd. Espoo. https://www.eke-electronics.com/wp-content/uploads/2022/08/EKE-Trainnet-Brochure-full_20220826.pdf (page 34). Accessed 12th July 2024.

El Rashidy R. A, and Van Gulijk C. (2016). *Driver Competence Performance Indicators Using OTMR*. Institute of Railway Research, University of Huddersfield. https://eprints.hud.ac.uk/id/eprint/28600/1/3417-7130-2-SM.pdf. Accessed 12th July 2024.

(EU) No 402/2013. (2013). *Commission Implementing Regulation (EU) No 402/2013 of 30 April 2013 on the common safety method for risk evaluation and assessment.*

(EU) No 1302/2014. (2014). *Commission Regulation (EU) No 1302/2014 of 18 November 2014 concerning a technical specification for interoperability relating to the 'rolling stock — locomotives and passenger rolling stock' subsystem of the rail system in the European Union.*

ETSI. (2018). *Universal Mobile Telecommunications System (UMTS); LTE; 3G Security; Specification of the 3GPP confidentiality and integrity algorithms; Document 1: f8 and f9 specification*. European Telecommunications Standards Institute ETSI TS 135 201

Evans A. W. (2017). *Fatal Train Accidents on Europe's Railways: 1980-2016.* Imperial College London.

GMRT2185. (2001). *Train Safety Systems*. Railway Group Standard GMRT2185, Iss. 2, 2001. Rail Safety and Standards Board.

Graves T. (2009). *Enterprise Architecture: A Pocket Guide*. IT Governance Publishing, Ely.

Griffith C. (2017). *Artificial Intelligence to Predict Accident Risk of Bus Drivers*. The Australian, 20th March 2017.

Guo M., Hu L. and Ye L. (2019). *Cognition and driving safety: How does the high-speed railway drivers' cognitive ability affect safety performance?* Transportation Research Part F: Traffic Psychology and Behaviour. 65. 10-22.

Haq Z. A. and Hasan Z. (2016). Eye-Blink rate detection for fatigue determination. IICIP 2016, 1st India International Conference on Information Processing, 1-5.

Ji Q. and Yang X. (2002). *Real-Time Eye, Gaze, and Face Pose Tracking for Monitoring Driver Vigilance*. Real-Time Imaging. 8. 357-377.

Kemp D., and Daw A. (2014). *INCOSE UK Capability Systems Engineering Guide*. UK Chapter of the International Council on Systems Engineering.

Kyriakidis M. (2013). *Developing a Human Performance Railway Operational Index to enhance safety of railway operations*. Imperial College London.

Langer C. (2016). *Analysing the root causes of Spain's high-speed derailment*. Rail Technology Magazine. https://www.railtechnologymagazine.com/Comment/analysing-the-root-causes-of-spains-high-speed-derailment. Accessed 12th July 2024.

LBC. (2018). *Train Safety Bosses Want To Put Spy Devices In Drivers' Cabs To Alert Them If They Doze*. Leading Britain's Conversation, 29 November 2018. https://www.lbc.co.uk/news/london/train-chiefs-putting-spy-devices-in-drivers-cabs. Accessed 12th July 2024.

Magazine Monitor. (2013). *Who, What, Why: What is 'highway hypnosis'?* BBC News, 4 December 2013. https://www.bbc.co.uk/news/magazine-25216601. Accessed 12th July 2024.

Masood S., Rai A., Aggarwal A., Doja M., and Ahmad M. (2018). *Detecting Distraction of drivers using Convolutional Neural Network*. Pattern Recognition Letters V.139 pp.79-85.

Meiring G. A. M. and Myburgh H. C. (2015). *A Review of Intelligent Driving Style Analysis Systems and Related Artificial Intelligence Algorithms*. Sensors 2015, 15(12), 30653-30682.

Microsoft. (2019). *Artificial Intelligence and road safety: A new eye on the highway — Facial recognition technology watches out for risks and monitors driver behavior*. Microsoft Asia News Center. https://news.microsoft.com/apac/features/artificial-intelligence-and-road-safety-a-new-eye-on-the-highway/. Accessed 12th July 2024.

Murray D. (2017). *Croydon tram bosses install infra-red beams to shine on drivers' faces to check they are awake — drivers to strike in protest*. Evening Standard, 1st November 2017. https://www.standard.co.uk/news/transport/croydon-tram-bosses-install-infrared-beams-to-check-drivers-are-awake-a3673341.html. Accessed 12th July 2024.

NEC. (2014). *NEC to implement solutions for SMRT Corporation to enhance bus service excellence — First telematics system in Singapore to monitor bus drivers' driving behavior*. https://www.nec.com/en/press/201408/global_20140805_02.html. Accessed 12th July 2024.

Neurocom. (2019). *Engine Driver Vigilance Telemetric Control System EDVTCS*. Neurocom, Moscow.

Nicol J, and Seglins D. (2014). *Freight train drivers report falling asleep on the job*. CBC News: October 7, 2014. CBC/Radio-Canada

NRIL. (2017). *Network Rail (Infrastructure) Ltd (NRIL) Health & Safety Management System*. Issue 4.0, May 2017. Network Rail (Infrastructure) Ltd.

NXP. (2020). Driver Monitoring Systems (DMS) and Occupant Monitoring Systems. NXP Semiconductors N.V. https://www.nxp.com/applications/solutions/automotive/adas-and-highly-automated-driving/driver-monitoring-systems-dms-and-occupant-monitoring-systems-:DRIVER-MONITORING-SYSTEMS. Accessed 12th July 2024.

ORR. (2010). *Guidance to Inspectors regarding the use of mobile phones / hand held electronic communication devices by train drivers*. RSD Internal Guidance RIG-2009-06, July 2010. Office of Rail and Road.

Poudel G. R., Innes C. R., Bones P. J., Watts R., and Jones R. D. (2014). *Losing the struggle to stay awake: divergent thalamic and cortical activity during microsleeps*. Hum Brain Mapp. 2014 Jan;35(1):257-69.

Progress Rail (2015). *Fatigue and distraction monitoring*. https://www.progressrail.com/

Reason J. T. (1990). *The Contribution of Latent Human Failures to the Breakdown of Complex Systems.* Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences. 327 (1241): 475–84. London

RAIB. (2016). *Rail Accident Report: Overturning of a tram at Sandilands junction, Croydon*. Report 18/2017. Rail Accident Investigation Branch.

RAIB. (2019). *Rail Accident Investigation Branch Annual Report 2018.* Department for Transport. Derby, UK.

RSSSG. (2018). *Long Term Passenger Rolling Stock Strategy for the Rail Industry*. Sixth Edition, March 2018. Rolling Stock Strategy Steering Group.

RSSB. (2005a). *Human Factors Study of Fatigue and Shift Work*. Research Report T059, Rail Safety and Standards Board.

RSSB. (2005b). T*rain Driver Mental Workload: The Train Driver Workload Principles Guidance Note*. In: *MWL Workload*. Ergonomics, I.F.O. and C.D.E. Ltd., p15. Rail Safety and Standards Board.

RSSB. (2008). *Understanding Human Factors — a guide for the railway industry*. Rail Safety and Standards Board.

RSSB. (2014). *Project S184 — Driver alertness monitoring systems*. Rail Safety and Standards Board.

RSSB. (2018). *TW5: Preparation and movement of trains: Defective or isolated vehicles and on-train equipment*. Rule Book Modules: Train Working, GERT8000-TW5 Iss. 9. Rail Safety and Standards Board.

RSSB. (2019). *The Machine Learning validation challenge: what it is and how to overcome the 'black box' criticism*. Rail Safety and Standards Board Featured story 24 January 2019. https://www.rssb.co.uk/about-rssb/insights-and-news/blogs/machine-learning-validation-challenge-how-to-overcome-the-black-box-criticism. Accessed 12th July 2024.

RSSB. (2021). *Project T1193 — T1193 Understanding the Functional Requirements for Train Driver Attention and Alertness Monitoring Devices*. Rail Safety and Standards Board.

Seeing Machines. (2019). *Real-time Driver Fatigue, Distraction and Accident Prevention Technology*. Seeing Machines, Fyshwick ACT, Australia.

Seglins, J. N. a. D., 2014. Freight train drivers report falling asleep on the job, s.l.: CBC.

Stagecoach Group PLC, 2011. UK Rail Industry - FAQs, s.l.: s.n.

Stopsleep. (2020). *Anti Sleep Alarm for Drivers*. PPS Diagnostika, model number S200.

SMI. (2014). *SMI Eye Tracking Glasses 2 Wireless*. SensoMotoric Instruments GmbH., Germany. https://www.mindmetriks.com/uploads/4/4/6/0/44607631/final_smi_etg2w_naturalgaze.pdf. Accessed 26th June 2024.

Tango F., and Botta M. (2013). *Real-Time Detection System of Driver Distraction Using Machine Learning. Intelligent Transportation Systems*. IEEE Transactions on Intelligent Transportation Systems 14(2):894-905.

The Train Guard. (2014). *Train and Railway Safety Systems*. March 9, 2014. https://thetrainguard.wordpress.com/2014/03/09/train-and-railway-safety-systems. Accessed 12th July 2024.

Toto S. (2012). *Sleep Buster: Japanese Company Develops Anti-Sleep Driver Seat Sheet.* TechCrunch.com, January 2, 2012.

Townsend J. (2019). *Tram Operations Ltd Presentation to Public Transport Liaison Panel.* Tram Operations Limited at Croydon Council Meeting, 27 February 2019. https://democracy.croydon.gov.uk/documents/s13859/Tram%20Operations%20LTD.pdf. Accessed 26th June 2024.

Tufuor T. (2017). *Using Active IR for eye detection and tracking*. Tufts University, ECE Senior Capstone Project.

von Jan T., Karnahl T., Seifert K., Hilgenstock J., and Zobel R. (2010). Don't Sleep and Drive — VW's Fatigue Detection Technology.

Whitlock A. (2002). *Driver Vigilance Devices: Systems Review*. Quintec Associates Limited, Hazelmere. August 30, 2002

Wi-Tronix. (2016). *Distracted Driving Detection for Train Safety*. [Video] Wi-Tronix LLC. https://www.youtube.com/watch?v=gaS8MQ3nt14. Accessed 12th July 2024.

Zen. (2019). *The Minimum Internet Speeds for Streaming Video in 2019*. Zen Internet Ltd. https://www.zen.co.uk/blog/posts/zen-blog/2019/04/18/the-minimum-internet-speeds-for-streaming-video-in-2019/. Accessed 12th July 2024.

Zhang X., Li J., Liu Y., Zhang Z., Wang Z., Luo D., Zhou X., Zhu M., Salman W., Hu G., and Wang, C. (2017). *Design of a Fatigue Detection System for High-Speed Trains Based on Driver Vigilance Using a Wireless Wearable EEG*. Sensors (Basel, Switzerland), 17(3), 486.

Appendix A. Requirements of Current Vigilance System

A.1 European Norm EN14033-1

Below is an extract of standard EN14033-1, “Railway applications — Track — Railbound construction and maintenance machines, Part 1: Technical requirements for running” (BS EN 14033-1:2017 Clause 14.11 on Driver's vigilance device):

The driver’s cab shall be equipped with a means to monitor the driver’s activity, and to automatically stop the machine when a lack of driver’s activity is detected.

The driver’s activity shall be monitored when the machine is in running mode and is moving. This monitoring is permitted to be done by noting the action of the driver on dedicated devices (pedal, push buttons, sensitive touches) and/or the driver's action on the Train Control and Monitoring System and/or the driver's vigilance by indirect means. When no action is monitored for more than 5 s, the vigilance monitoring shall start.

After a time not longer than 60 s without detecting driver’s activity the lack of driver's activity shall be triggered.

Before triggering a lack of driver’s activity, a warning shall be given to the driver, in order for him to have the possibility to react and reset the system.

The system should have the information “lack of driver’s activity triggered” available for being interfaced to other systems (e.g. the radio system).

The detection of the lack of the driver’s activity is a function that shall be subject to a reliability study considering the failure mode of components, redundancies, software, periodic checks and other provisions, and the estimated failure rate of the function (lack of driver’s activity as specified above not detected) shall be provided in the technical documentation. When existing systems with known service experience are used, it is permissible that this study is not necessary.

Specification of actions triggered at machine level when a lack of driver’s activity is detected:

- *a lack of driver’s activity when the machine is in running mode and is moving (criterion for movement detection is at a low speed threshold) shall lead to a full service brake or an emergency brake application on the machine;*
- *in case of application of a full service brake, its effective application shall be automatically controlled and in case of non-application, it shall be followed by an emergency brake.*

It is permitted to have the function described in this clause fulfilled by the in-cab signalling and control systems.

A.2 Commission Regulation (EU) No 1302/2014

Below is an extract of Commission Regulation (EU) No 1302/2014 of 18 November 2014 concerning a technical specification for interoperability relating to the rolling stock — locomotives and passenger rolling stock subsystem of the rail system in the European Union (Clause 4.2.9.3.1 on Driver's Activity Control Function):

(1) The driver's cab shall be equipped with a means to monitor the driver's activity, and to automatically stop the train when a lack of driver's activity is detected.

(2) Specification of the means to monitor (and detect a lack of) the driver's activity:

The driver's activity shall be monitored when the train is in driving configuration and is moving (criterion for movement detection is at a low speed threshold); this monitoring shall be done by controlling the action of the driver on dedicated devices (pedal, push buttons, sensitive touches...) and/or his action on the Train Control and Monitoring System and/or his vigilance by indirect means.

When no action is monitored during more than a time of X seconds, a lack of driver's activity shall be triggered.

The system shall allow for the adjustment (at workshop, as a maintenance activity) of the time X within the range of 5 seconds to 60 seconds.

When the same action is monitored continuously for more than a time not higher than 60 seconds, a lack of driver's activity shall also be triggered.

Before triggering a lack of driver's activity, a warning shall be given to the driver, in order for him to have the possibility to react and reset the system.

The system shall have the information ―lack of driver's activity triggered‖ available for being interfaced to other systems (i.e. the radio system).

(3) Additional requirement:

The detection of the lack of the driver's activity is a function that shall be subject to a reliability study considering the failure mode of components, redundancies, software, periodic checks and other provisions, and the estimated failure rate of the function (lack of driver's activity as specified above not detected) shall be provided in the technical documentation.

(4) Specification of actions triggered at train level when a lack of driver's activity is detected:

A lack of driver's activity when the train is in driving configuration and is moving (criterion for movement detection is at a low speed threshold) shall lead to a full service brake or an emergency brake application on the train. In case of application of a full service brake, its effective application shall be automatically controlled and in case of non application, it shall be followed by an emergency brake.

Notes:

— It is allowed to have the function described in this clause fulfilled by the CCS Subsystem.

— As a transitional measure, it is also allowed to install a system of a fix time X (no adjustment possible) provided that the time X is within the range of 5 seconds to 60 seconds.

— A Member State may ask for a maximum fix time for safety reasons, but in any case it cannot prevent the access to a railway undertaking that using a higher time Z (within the range specified), unless that Member State is able to demonstrate that the national safety level is endangered.…

Appendix B. Railway Industry Acronyms

Acronym	Expansion
AWS	Automatic Warning System
CSM-RA	Common Safety Method on Risk Evaluation and Assessment
DAS	Driver Advisory System
DCO	Driver Controlled Operation
DRM	Driver Resource Manager
DSD	Driver Safety Device
DVD	Driver's Vigilance Device
ERTMS	European Railway Traffic Management System
ETCS	European Train Control System
GSM-R	Global System for Mobile Communications-Railway
LOC&PAS TSI	Locomotive & Passenger Rolling Stock Technical Specification for Interoperability
MoE	Measure of Effectiveness
MoP	Measure of Performance
ORR	Office of Rail Regulation
OTCM	On-Train Camera/Monitors
OTMR	On-Train Monitoring Recorders
RAIB	Rail Accident Investigation Branch
RDG	Rail Delivery Group
RSSB	Rail Safety and Standards Board Ltd
SPAD	Signal Passed at Danger
TBC	Traction/Brake Controller
TCMS	Train Control and Monitoring System
TOCs	Train Operating Companies
TPWS	Train Protection and Warning System
TfL	Transport for London