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D2.2

Technologies for safety interventions and assessment of their effectiveness

Safe tolerance zone calculation and interventions for driver-vehicle-environment interactions under challenging conditions

iDREAMS

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Glossary and abbreviations

Abbreviation	Description	Abbreviation	Description	Abbreviation	Description
ADAS	Advanced Driver Assistance System	GMM	Gaussian Mixture Model	PERCLOS	Percentage of Eye Closure
AI	Artificial Intelligence	GPRS	General Packet Radio Service	PHYD	Pay How You Drive
AMiVIS	Adaptive Multimodal in-Vehicle Information System	GPS	Global Positioning System	PPG	Photoplethysmogram
ANFIS	Adaptive Neuro-Fuzzy Inference System	GSM	Global System for Mobile Communications	PSE	Power Spectral Entropy
APPM	As Pay Per Mile	GSR	Galvanic Skin Response	PU	Perceived Usefulness
ATP	Automatic Train Protection	GUI	Graphical User Interface	RFID	Radio Frequency Identification
AWS	Automatic Warning System	HMM	Hidden Markov Models	RMS	Root Mean Square
BCALs	Behavioural Context Addressable Loggers in the Shell	HR	Heart Rate	RPM	Rate Per Mille
BDWS	Blind Spot Detection and Warning System	HRV	Heart Rate Variability	RR	Respiration Rate
BI	Breathing Intensity	HUD	Head-Up Display	RT	Reaction Time
BIS	Belt In Seat	IAA	Internationale Automobil-Ausstellung	RTOS	Real Time Operating System
BP	Blood Pressure	IHR	Instantaneous Heart Rate	SDT	Self Determination Theory
BRPM	Beat Rate per Minute	IoT	Internet of Things	SE	Sample Entropy
BT	Body Temperature	ISA	Intelligent Speed Adaptation	SI	Social Influence
CAN	Controller Area Network	ISPS	Intelligent Speeding Prediction System	SP	Speed
CDMA	Code Division Multiple Access	ITS	Intelligent Transportation Systems	SPAD	Signal Passed At Danger
CID	Central Information Display	IVDR	In-Vehicle Data Recorders	SPP	Serial Port Profile
CV	Connected Vehicle	LCD	Liquid Crystal Display	ST	Skin Temperature
CWS	Collision Warning Systems	LIDAR	Light Detection And Ranging	SUS	System Usability Scale
DMAS	Driving Monitoring Assistance Systems	LF/HF	Low Frequency/High Frequency	SVM	Support Vector Machine
DMS	Driver Monitoring System	LDWS	Lane Departure Warning System	TAM	Technology Acceptance Model
DNs	Distress Notifications	MEMS	Microelectromechanical System	TCP	Transmission Control Protocol
DSAS	Driver's Smart Advisory System	MHYD	Manage How You Drive	TIMs	Traveller Information Messages
DTC	Diagnostic Trouble Codes	ML	Machine Learning	TMC	Transtheoretical Model of Change
DTW	Dynamic Time Warping	MOST	Media Oriented SystemsTransport	TP	Temperature
DVR	Digital Video Recorder	n	Number of participants in the experiment	TPB	Theory of Planned Behaviour
ECG	Electrocardiogram	NN	Neural Network	TPS	Train Protection System
ECU	Electronic Control Units	OAMS	Optalert Alertness Monitoring System	TPWS	Train Protection and Warning System

EDA	Electro-Dermal Activity	OBD	On-Board Diagnostic	TTC	Time To Collision
EE	Effort Expectancy	OBSD	On-Board Smart Box	UBI	Usage-Based Insurance
EEG	Electroencephalogram	OEM	Original Equipment Manufacturer	UTAUT	Unified Theory of Acceptance and Use of Technology
EMG	Electromyogram	PAYD	Pay As You Drive	UMDA	Unified Model of Driver Acceptance
ENG	Electroneurogram	PAYG	Pay As You Go	VII	Vehicle-Infrastructure Integration
EOG	Electrooculography	PBC	Perceived Behavioural Control	V2I	Vehicle-to-Infrastructure
ER	Early Recognition	PE	Performance Expectancy	V2V	Vehicle-to-Vehicle
FCW	Forward Collision Warning	PEOU	Perceived Ease of Use	VGA	Video Graphics Array

Executive summary

This deliverable aims to compare and contrast the available technologies for safety interventions both in real-time (i.e. during a driving session) as well as post-trip. These safety interventions will be a significant module within the i-DREAMS project, as they will inform or warn the driver with regards to the real-time safety level, and will provide a gamified coaching platform to enhance longtime driving performance or skills. The findings of this review, form the results of Task 2.2, within WP2 of the i-DREAMS project.

Initially, the definition of a safety intervention is provided based on the literature, and the importance of a correct intervention strategy is highlighted. Furthermore, theoretical principles related to acceptance and performance are analyzed, and recommendations for designing the i-DREAMS intervention strategy are given. It was shown that acceptance should be pursued closely with the operators participating in the simulator and naturalistic driving experiment using survey and observational techniques, and that training could enhance acceptance of technologies. With regards to performance, a multi-stage multimodal approach on feedback was found to be an advantageous option.

Real-time and post-trip intervention technologies were assessed based on the criteria of acceptance and effectiveness distinctively for each mode in the i-DREAMS project (i.e. car, truck, bus and train). For each of the modes, commercially available technologies, as well as interventions tested within the academic literature, were overviewed and assessed. At the end of each corresponding mode-specific review, recommendations on the intervention technologies per mode are given, and cross-modal considerations and differences between professional and non-professional drivers are discussed. More details on legislation, regulations, as well as targeted theories on interventions for professional drivers are discussed in the sections for truck and bus operators.

The in-depth literature review revealed that eye-tracking and similar visual sensors are deemed the most efficient for monitoring driver state and provided interventions in real-time with auditory or visual messages. Furthermore, if such devices are of small size or are connected with a smartphone application they can easily be modified and transferred, but there is almost a concern on practical implementations of these tools. However, the state-of-the-art in such intervention technologies are application specific and do not provide an holistic intervention approach to driver performance degradation.

Gamification and an appropriate reward or penalty system were proven to be the most effective strategy for post-trip interventions, as it was found that they keep drivers motivated in order to enhance their driving skills. With regards to professional drivers, coaches can educate them on an optimal driving behaviour, after receiving an overview of drivers' performances. Nevertheless, it should be mentioned that in trucks and buses, interventions are usually part of a broader framework (i.e. including driver coaching and management commitment) and the effects of such interventions cannot be taken into account in isolation for accomplishing a sufficienrt safety culture changeIt is worth mentioning that there was not found a complete post-trip intervention solution massively developed or tested in real-world environments.

For each of the considered transportation modes suggestions were made with regards to monitoring technologies and commercial solutions. The provided recommendations and considerations for the safety interventions to be included in the i-DREAMS platform, need to also be considered for the mathematical formulation of the Safety Tolerance Zone. In addition, a compromise needs to be found between the estimation of the safety level, the triggering and information provided in real-time, and the analytics or coaching provided after the end of driving trips.

1 Introduction

1.1 About the project

The overall objective of the i-DREAMS project is to setup a framework for the definition, development, testing and validation of a context-aware safety envelope for driving, within a smart Driver, Vehicle & Environment Assessment and Monitoring System (i-DREAMS). The main issue is to determine a "Safety Tolerance Zone" and monitor if drivers are within acceptable boundaries of safe operation. Taking into account driver background factors and real-time risk indicators associated with the driving performance as well as the driver state and driving task complexity indicators, a continuous real-time assessment will be made to bring the driver back into a safe area, while driving or to improve driving performance during future trips, through information and warnings. Moreover, safety-oriented interventions will be developed to inform or warn the driver during his driving performance in an effective way as well as on an aggregated level after driving through an application and web-based gamified coaching platform.

Figure 1 summarizes the conceptual framework, which will be tested in a simulator study and three stages of on-road trials in Belgium, Germany, Greece, Portugal and the United Kingdom with a total of 600 participants representing car, bus, truck and train drivers respectively. Specifically, the Safety Tolerance Zone is subdivided in three segments, i.e. 'normal driving', the 'danger phase', and the 'avoidable accident phase'. For the real-time determination of this safety tolerance zone, the monitoring module in the i-DREAMS platform will continuously register and process data for all the variables related to the context and to the vehicle. Regarding the operator however, continuous data registration and processing will be limited to mental state and behaviour. Finally, it is worth mentioning that data related to operator competence, personality, socio-demographic background, and health status, will be collected via survey questionnaires.

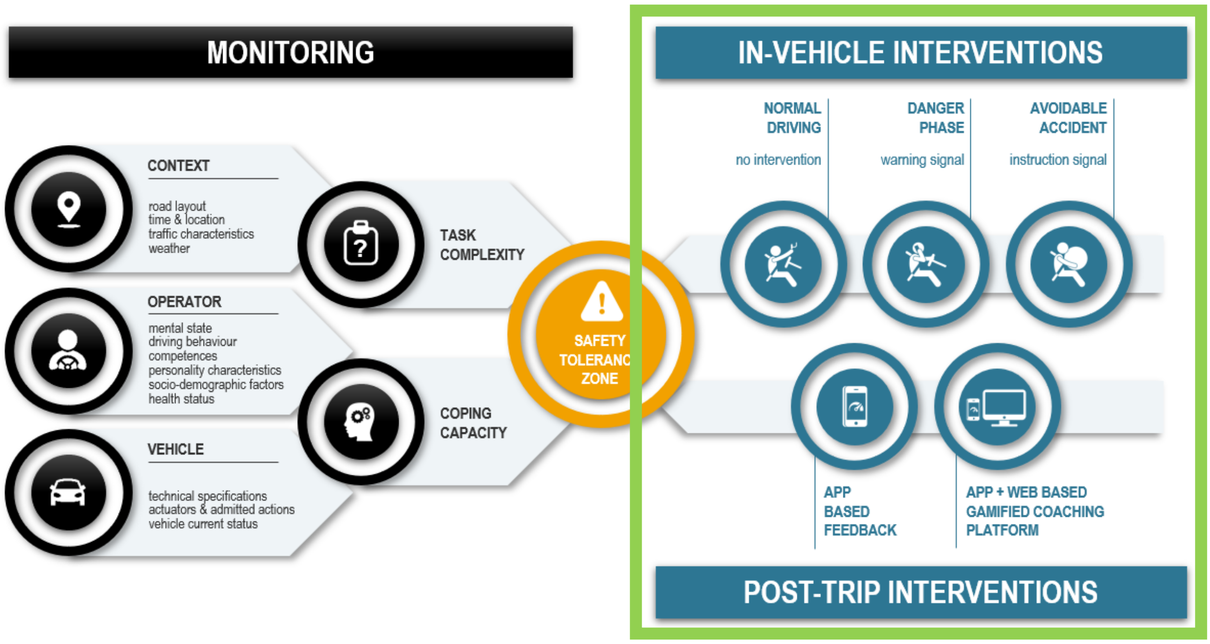

Figure 1: Conceptual framework of the i-DREAMS platform. The green dotted frame indicates the thematic scope of this deliverable (see section 2.2)

The i-DREAMS platform, focuses on the implementation of two different types of highly customized interventions. Undoubtedly, this is an important asset which offers the possibility to implement both real-time and post-trip interventions to improve road safety and driving performance. To begin with, real-time interventions are proposed to keep fleet operators as much as possible within the "Safety Tolerance Zone", through in-vehicle warnings (e.g. haptic, auditory or visual). On the other hand, post-trip interventions provide personalized feedback on behavioural indicators of risk through a smartphone application or a web-platform. The most effective intervention type is identified in relation to the nature of the risk and this is used to modify the application of future interventions thereby implementing a personalised safety intervention program.

The key output of the project will be an integrated set of monitoring and communication tools for intervention and support, including in-vehicle assistance and feedback and notification tools as well as a gamified platform for self-determined goal setting working with incentive schemes, training and community building tools. Finally, a user-license Human Factors database with anonymized data from the simulator and field experiments will be developed.[1]

As a first step towards developing the i-DREAMS intervention strategy, this deliverable aims at reviewing vehicle technologies and applications for safety interventions associated with risk prevention and mitigation. This is achieved by critically comparing and contrasting existing systems and technologies to inform road users either in real-time or post-trip. Such technologies should be directed at enhancing knowledge, attitudes, perception and eventually safety behaviour. Based on the personalized identification of driving performance or vehicle operation, both real-time and post-trip interventions for different transport modes are proposed. The objective of this deliverable is to provide technologies for safety interventions and select the criteria of the most appropriate techniques and challenges. The assessment of their effectiveness, reliability and acceptance is also discussed.

1.2 About this report

The main topics that are being mentioned in the present deliverable are the state-of-the-art technology for safety interventions, as well as the assessment of their effectiveness. This work addresses the right half of Figure 1 i.e., the safety interventions, including real-time and post-trip interventions in terms of effectiveness, acceptance and overall assessment for the project.

The objective of this document is dual:

i. To critically review and assess the state-of-the-art in user feedback and safety intervention technology for each of the four modes (cars, buses, trucks and trains) considered in the i-DREAMS project, and
ii. To provide recommendations on a set of the corresponding intervention systems deemed suitable for practical implementation both in real-time and post-trip.

To achieve those objectives, a comprehensive literature search is conducted in order to identify technologies, measurement methods and their targeted operator state factors. Technologies corresponding to the four modes included in the i-DREAMS project (i.e. car, truck, bus and train) are distinctively examined in order to review technologies that might perform better in a

[2] Further general project information can be found on the website: https://idreamsproject.eu

specific mode. Bus interventions were investigated separately, but several feedback technologies found to be similar with those for professional truck drivers. Nevertheless, an examination of the transferability of the results to other i-DREAMS transportation modes is also documented. Where applicable, potential differences on the utilization of interventions between professional drivers versus and non-professional drivers is considered, as this is an integral part of the i-DREAMS project.

Research questions that are attempted to be answered through this deliverable are:

- What is a safety intervention and what is the impact of an intervention in safety-critical scenarios?
- How can we evaluate safety interventions in terms of effectiveness and acceptance?
- Which are the most effective interventions in real-time and post-trip for each of the four modes considered in the project?
- Are there similarities in the functionality and effectiveness of interventions between different modes?
- Are there differences in intervention strategies between professional and non-professional drivers?

With regards to its structure, this report begins with a theoretical foundation (Chapter 3), where a representative definition of a safety intervention is given. Along with this definition, Chapter 3 also provides a discussion on the importance of a safety intervention and a taxonomy of intervention approaches to promote road safety and eco-efficiency is developed. The most important intervention approaches situated in the domain of monitoring and assessment are identified, described, categorized and discussed. The legal framework for professional drivers stipulating the minimum requirements is also analysed. Also, intervention approaches that can be situated in the domain of employee education and training are discussed. The use of gamification within safety interventions as well as the most reliable factors targeted for interventions and the necessity of an efficient intervention strategy in i-DREAMS are also provided. Chapters 4 and 5 include the main outcomes of this report which relate to the review and assessment of real-time and post-trip interventions respectively. Finally, at the end of this work (Chapter 6), conclusions and considerations with regards to the most useful technologies for calculation of the "safety tolerance zone" are described.

2 Theoretical foundation of safety interventions

2.1 Definition of a safety intervention

Driving behaviour is an important factor in road safety. For example, speed not only affects the severity of a crash, but is also related to the risk of being involved in a crash (Aarts and Schagen, 2006). In a very short amount of time, with the evolution of technology, a few driver monitoring systems and gamified web-platforms or smartphone applications were introduced in order to record driving performance, provide personalized feedback to the driver and focus on key risk indicators. Thus, drivers are now able to identify their weak points, improve their driving style and promote maximum road safety through interventions.

According to Zaira and Hadikusumo (2017) a safety intervention is a means for improving safety behaviour. Furthermore, Daignault and Delhomme (2011) claimed that the objective of road safety interventions was to convince drivers that offending behaviors were intrinsically dangerous and dissuade them from violating while driving by means of surveillance. A few interventions which used a range of methods such as training, education or technology, attempted to equip drivers with the skills and attitudes they needed to become safer, more efficient and therefore eco-friendly (Russell et al., 2011; Kinnear et al., 2013). As a result, the following definition could be developed:

"A safety intervention is a provided set of information, guidance, warnings, feedback or notifications that drivers receive (either in real-time or post-trip), based on a personalized identification of driving episodes with the aim of risk prevention and mitigation". Safety interventions are developed to prevent drivers from risky driving behaviour and decrease the collision rate or the probability of occurrence of crashes, damage, costs and injuries.

Real-time interventions are in-vehicle interventions which are triggered while travelling when specific conditions arise. These interventions usually take the form of in-vehicle auditory, visual or haptic warnings and are used to maintain and increase the safety and comfort level of the driver. These real-time warnings are usually delivered via embedded devices or smartphones and can also become personalised by identifying driver-specific physiological indicators and the corresponding driving performance measurements. Usual factors targeted through real-time interventions, include mental state (e.g. fatigue, drowsiness, distraction, stress and emotions) as well as driving behaviour in terms of speed, harsh acceleration/breaking, safety distance, lane keeping and alcohol abuse (e.g. Beckjord and Shiffman, 2014).

On the contrary, post-trip interventions provide feedback after the end of a trip, and on the principle that vehicle operators self-monitor their driving history, identify their behavioural weaknesses and set goals in a self-determined manner in order to gradually build up their skills. The aim of such retrospective interventions is to change drivers' behaviour,and keep them motivated to operate their vehicle in a safer and more eco-efficient way over a longer period of time. Post-trip interventions can be usually delivered through a combination of a smartphone application and a gamified web-based platform on top of personalized feedback. These smartphone and web-platform applications offer post-drive feedback and scoring, based on the personal performance on a series of risk related behavioural parameters. Some of the major factors targeted through post-trip interventions refer not only to driver states like distraction, fatigue or aggressiveness but also to driving performance such as excessive speeding, harsh acceleration, breaking or cornering, mobile phone use and driving during rush or risky night hours.

2.2 The importance of choosing the right intervention

The choice of a correct intervention could prove crucial for the enhancement of road safety in everyday life. The two aforementioned types of interventions (i.e. real-time and post-trip) aim at enhancing knowledge, attitudes, perception and behavioural reaction of drivers with respect to safety-related technologies, situations and behaviours. Through immediate (real-time) or delayed (post-trip) feedback, driving skills during future trips could be improved and the driver could be reinstated in a safe driving field, in which not only the driver but also the passengers would be safe. The main characteristics that are essential for the success of an intervention tool are its performance (i.e the effectiveness of the intervention) and its acceptance from the user (including usability and satisfaction;Yardley et al., 2015). The more these criteria are fulfilled, the better the effect on safety is. This was derived from the fact that if an objectively effective intervention is not easily useable or accepted by one driver, its effect would not be appreciated or demonstrated. As a result, finding a balance between maximizing effectiveness, and keeping acceptance, usability and driver satisfaction at high levels during and after the trip is beneficial for operators as well as the whole traffic ecosystem.

2.3 Taxonomy of interventions

This section aims to give a comprehensive overview of the different interventional approaches that have been described in the literature to promote SMART driving as a way to improve road safety and eco-efficiency. The scope was not limited to approaches that are more typically applied in the context of basic training (to obtain a category C-related driving licence, see Directive 2006/126/EC and Directive 2018/645) or in the context of professional training - whether initial qualification or periodic training (to obtain a so-called code 95, see Directive 2003/59/EC and Directive 2018/645) - alone. Instead, a more open perspective was adopted and intervention approaches that are applied outside the context of truck operator compliance with the minimum requirements imposed by the EU-Directives discussed in the previous section are also included.

More in detail, the purpose is to describe and classify intervention approaches, as well as to bring them together into a logically structured taxonomy of interventions. The promotion of road safety and eco-efficiency among professional truck drivers cannot be isolated from the working context in which they operate on an almost daily basis. Keeping the importance of workplace environment in mind, a framework that was developed and proposed by Mitchell et al. (2012) on professional fleet safety management is discussed. That framework inventoried a broad set of strategic-, tactic-, and operational actions that can be adopted to improve occupational road safety in professional vehicle fleets.

Even though originally meant to serve as an audit tool in the sector of light vehicle fleets, the framework itself is applicable as well to other sectors of (freight) transport and logistics, like for instance heavy haulage. The latter can be derived, from the well-known synthesis studies published by the Commercial Truck and Bus Safety Synthesis Program (CTBSSP). The CTBSSP was established in the US by the Federal Motor Carrier Safety Administration (FMCSA) and is administered by the Transportation Research Board (TRB). The CTBSSP was authorized in late 2001 and began in 2002 in support of the FMCAs safety research programs. On an annual basis, a synthesis report is released that addresses issues in the domain of commercial truck and bus safety (see for instance Knipling et al., 2003). From that series of synthesis reports, it becomes clear that the set of actions contained by the framework of Mitchell et al. (2012), is highly relevant for a wide variety of professional fleets, whether light- or heavy vehicles are involved.

One of the reasons to use the framework of Mitchell et al. (2012) as the starting point of the proposed intervention taxonomy, was the scientific orientation of the work out of which the framework resulted. Methodology-wise, the authors explain that the framework was developed based on triangulation of information from a review of the literature on fleet safety management practices and from semi-structured interviews with both fleet managers and fleet drivers. On top of that, a useability assessment of the framework was conducted in five different organizations. In the next paragraph, the framework of Mitchell et al. (2012) is discussed more in detail.

Five basic intervention domains

For more than four decades, the issue of how to improve occupational health and safety has attracted attention from practitioners, researchers and policy makers worldwide (e.g. Taylor, 2010; Patankar et al., 2012). The topic has also been intensively studied in the sector of transportation of goods and persons where evidently, the management of professional vehicle fleets (whether air, maritime, rail or road) is a key-activity (Nævestad et al., 2018). Even though in their review of best practice road safety initiatives in the corporate and/or business environment, Haworth et al. (2000) observed that management of fleet vehicles traditionally focused on asset management rather than occupational health and safety management (OHS), the interest in OHS has increased substantially. This probably relates to available statistics showing that work-related vehicle crashes are a very common cause of occupational injury. As indicated by Nævestad et al. (2015) and Adminaite et al. (2017), it is estimated that over a third of all fatal road accidents occurring in Europe are work-related. As argued by Mitchell et al. (2012), there is considerable knowledge about risk factors for vehicle crashes, and interestingly, a range of these factors are amenable to control by employers.

One of the crucial and consistent findings in the field of OHS, is that building and sustaining employee health and safety is to a large extent dependent on how the workplace environment is oriented towards health and safety (Zohar, 2010). As for the latter, a conceptual distinction is made between a company's so-called 'safety culture' on the one hand, and safety' climate' on the other hand. In the words of Guldenmund (2007), safety climate should be distinguished from safety culture in a sense that the former is a manifestation or 'snapshot' of the latter. Guldenmund further explains that safety climate actually reflects workforce perceptions of the organizational safety-related atmosphere, which implies that safety climate is a more superficial and transient concept than safety culture. The essence of safety culture is considered to be reserved for the core of an organization's culture, which is to be deciphered from many sources amongst which (organizational) climate. This is in line with work where the concept of organizational safety culture is formally defined as "safety relevant aspects of culture in organizations" (e.g. Hale, 2000; Antonsen, 2009; Nævestad, 2010), and where these aspects have been said to refer to a range of different cultural phenomena such as "observed behavioural regularities when people interact (language, customs and traditions, rituals), group norms, espoused values, formal philosophy, rule of the game, climate, embedded skills, habits of thinking, mental models, linguistic paradigms, shared meanings and 'root' metaphors or integrating symbols" (see Schein, 1992: p.8 in Guldenmund, 2000: p. 225). As argued by Huang et al. (2018) safety climate is generally defined as employees' shared perceptions of their organization's policies, procedures, and practices in regards to the value and importance placed on safety (see Zohar, 2008, 2010). Thus, paraphrased in somewhat different terms: from a conceptual point of view, safety climate is situated at a lower level of abstraction than safety culture since it encapsulates the perception of more visible safety-related organizational properties, such as the extent to which there are formal procedures to structurally manage occupational health and safety.

Organizations can differ in terms of how strong (or weak) their safety culture and safety climate is developed. One well-known instrument to capture the level of variety in this regard, is the so-called Safety Culture Ladder (see for instance Taylor, 2010). It distinguishes between organizations in function of how their safety culture can be qualified. In case an organization has only few safety rules, and only little or no management commitment to either safety or leadership in setting safety standards, and workforce is expected to look after itself regarding keeping safe ('accidents are part of doing the job'), the organization's safety culture is qualified as 'pathological'. Organizations starting to take safety seriously but taking action only after incidents have occurred, have a 'reactive' safety culture. Organizations where safety is treated very seriously and where there are management systems available as well as data collection have a 'calculative' safety culture. Organizations where people try to avoid accidents and start to take a bottom-up approach, have a 'proactive' safety culture. Finally, organizations where safety culture is qualified as 'generative' are typically high reliability, low-risk organizations where safety is fully integrated into all business functions risk portfolios. Safety is considered important at all staff levels and there is very high degree of team working and safety-focused dialogue throughout the organization. There are safety trainings, effective feedback systems and procedures affecting safety that are under constant scrutiny.

Turning now to the fleet safety management framework proposed by Mitchell et al. (2012), the authors argue that organizations better performing in terms of safety culture and safety climate, are typically organizations where a series of strategic-, tactic-, and operational initiatives identified as important based on literature review and semi-structured interviews with fleet managers and fleet drivers, are implemented at a high standard level. More specifically, at the highest level five different intervention domains can be distinguished according to the authors. Within each of these intervention domains, strategic action domains can be identified, which in turn can be further translated into specific operational actions, all aimed at promoting occupational road safety in professional vehicle fleets. In order to keep a clear overview, each of the five intervention domains were visualized, together with their underlying strategic-, and operational actions in five separate figures. Figure 2 represents the strategic-, and operational actions that fall under the first intervention domain, i.e. 'management, systems and processes'.

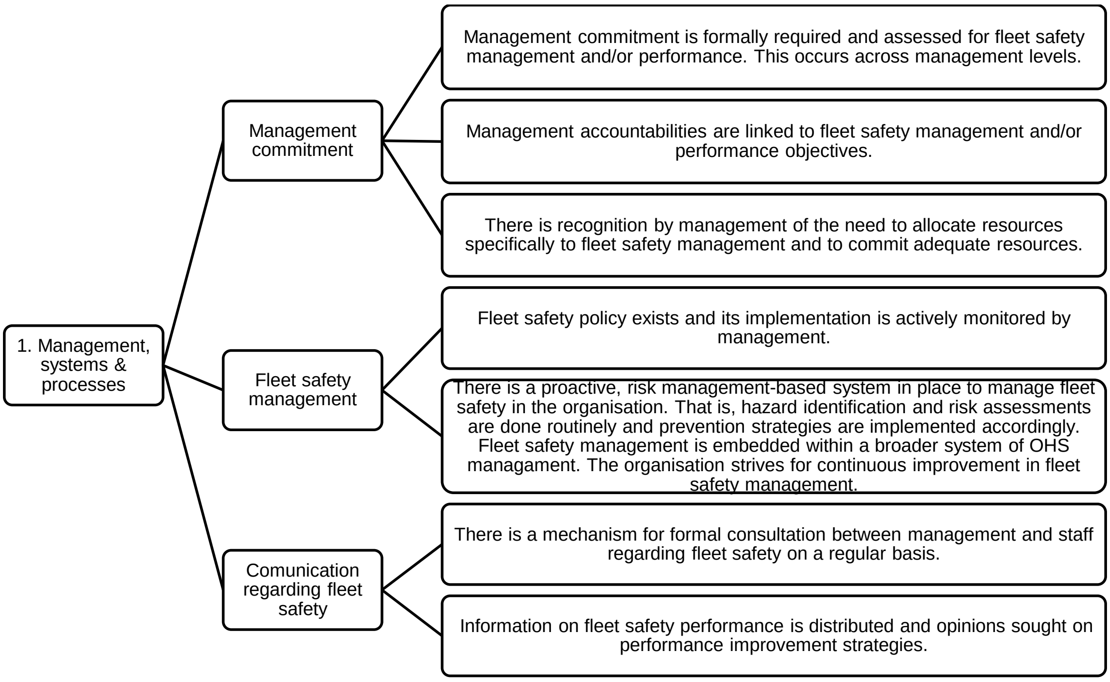

Figure 2 : Strategic- and operational actions falling under intervention domain 1 'Management, systems & processes' as proposed by Mitchell et al. (2012)

According to Mitchell et al. (2012), organizations that perform well in terms of safety culture and safety climate are characterized by management that demonstrates leadership and commitment to fleet safety. Fleet safety is managed in a pro-active way with consultation between management and workers regarding fleet safety issues and employees are actively involved in decision making processes. More specifically, three strategic actions can be related to the first intervention domain. These are management commitment, fleet safety management, and communication regarding fleet safety. For each of these three strategic actions, a set of operational initiatives can be implemented. In more specific terms, this domain relates to the idea that organizations conduct crash investigations for at-fault vehicle crashes involving workers. Moreover, systems are in place to monitor fleet safety performance (the driver behaviour of employees included therein), and the organization is able to follow-up on at-fault vehicle crash trends. Also, mechanisms are present to recognize good driving performance and to respond to driver infractions. Within this intervention domain as well, three strategic actions can be implemented, i.e. vehicle crash and incident investigation, monitoring fleet safety performance, and performance monitoring and recognition. Here as well, different operational actions can be adopted. Figure 3 shows an intervention domain 2, i.e. employee recruitment, training and education together with its respective strategic- and operational actions.

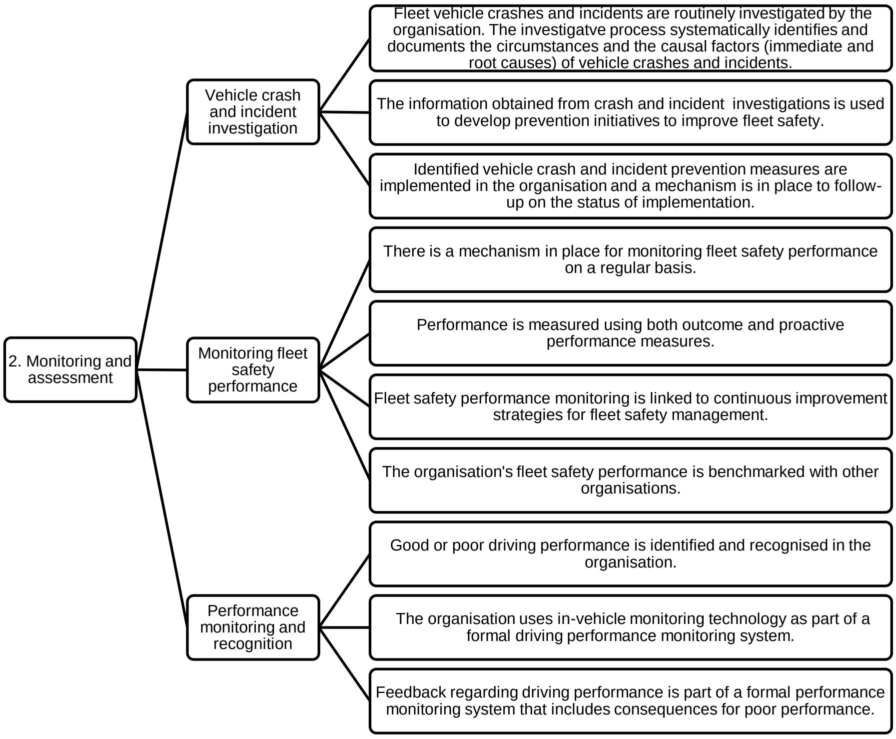

Figure 3: Strategic and operational actions falling under intervention domain 2 'Monitoring and assessment' as proposed by Mitchell et al. (2012)

Figure 4 depicts an intervention domain 3, i.e. employee recruitment, training and education together with its respective strategic- and operational actions.

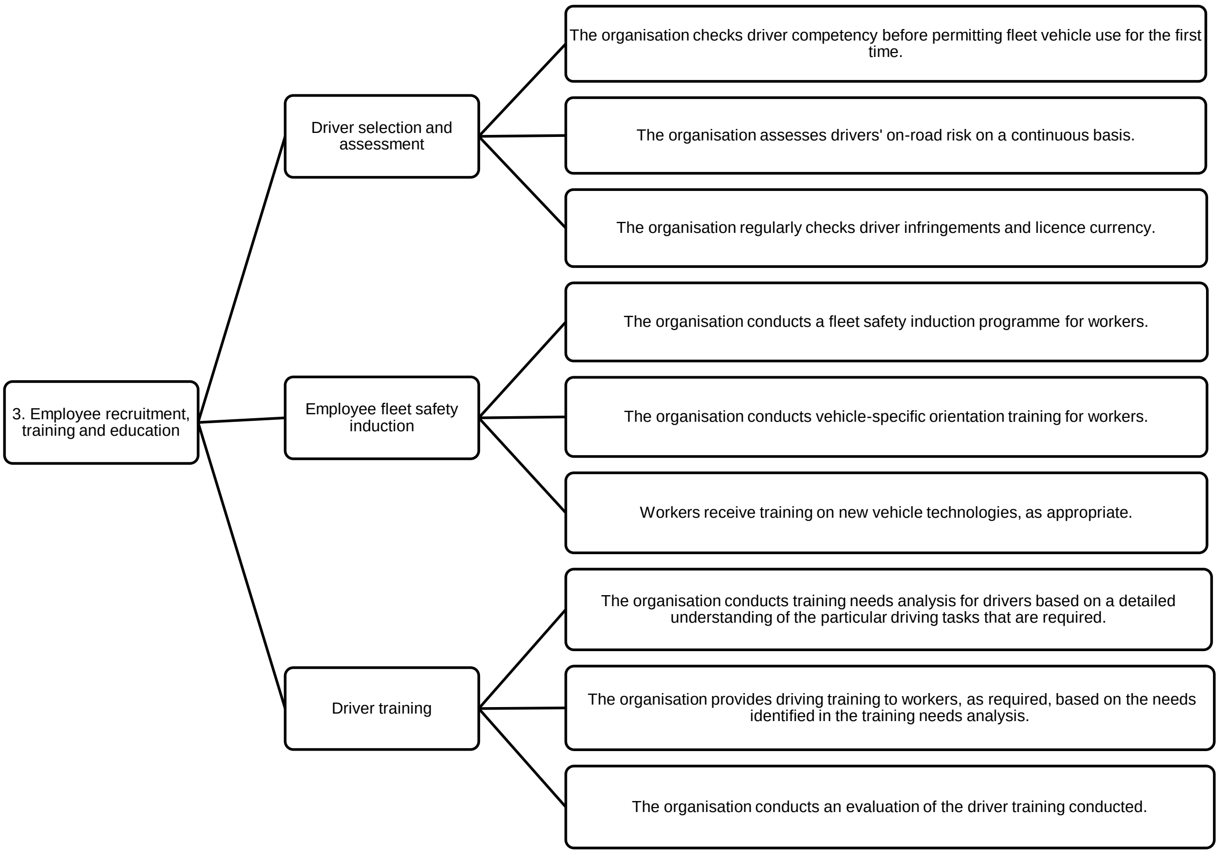

Figure 4: Strategic- and operational actions falling under intervention domain 3 'Monitoring and assessment' as proposed by Mitchell et al. (2012)

The third intervention domain implies organizations have systems and protocols in place to select drivers and to conduct fleet safety and vehicle–specific induction programs for their workers. Furthermore, the organization identifies, conducts, and evaluates driver training programs for employees, as required. Accordingly, the three strategic actions under this intervention domain are driver selection and assessment, employee fleet safety induction, and driver training. Figure 5 shows intervention domain 4, i.e. vehicle technology, selection and maintenance and its respective strategic- and operational actions.

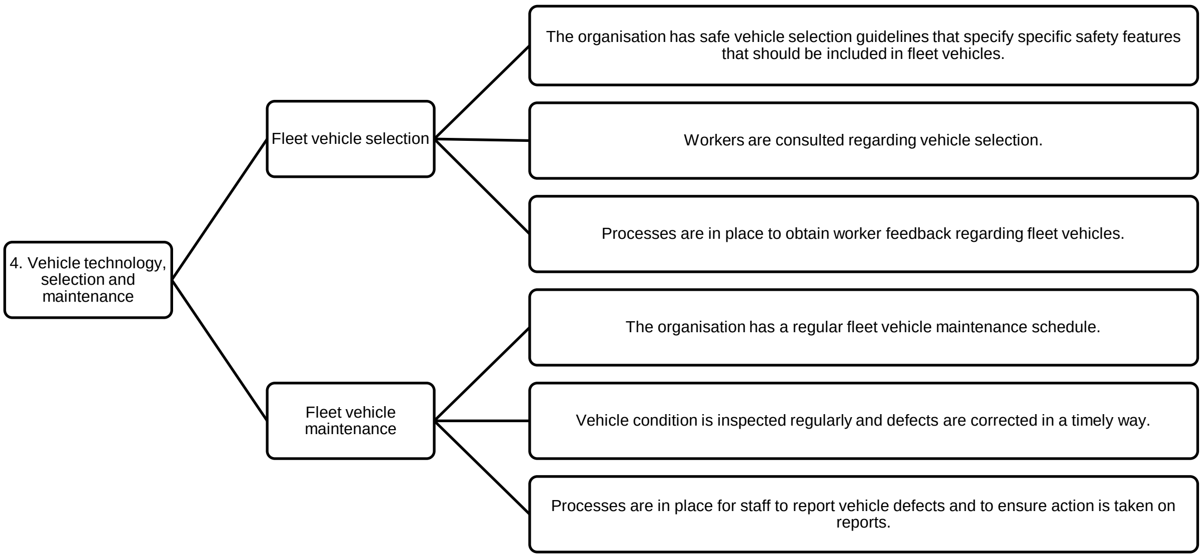

Figure 5: Strategic and operational actions falling under intervention domain 4 'Vehicle technology, selection and maintenance' as proposed by Mitchell et al. (2012)

Intervention domain 4 implies organizations have fleet vehicle selection guidelines and regularly conducted programs of fleet vehicle maintenance. Figure 6 shows which more specific operational actions can be implemented regarding fleet vehicle selection and maintenance.

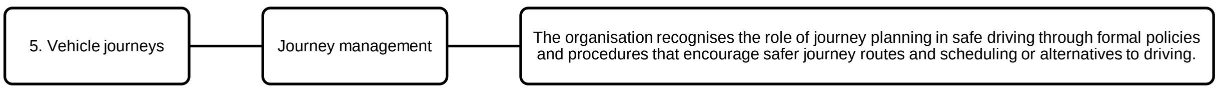

Figure 6: Strategic- and operational actions falling under intervention domain 5 'Vehicle journeys' as proposed by Mitchell et al. (2012)

Intervention domain five implies that organizations recognize the role of journey planning with inclusion of the identification of safe routes and risk factor management. Based on the analysis of the legislative framework, it was clear that professional competence actually requires truck drivers not only to adopt a safe driving style, but an eco-efficient driving style as well, the two being narrowly related to each other (e.g. Young et al., 2011). The interest of adopting the framework of Mitchell et al. (2012) as an outlining blueprint for the development of an intervention taxonomy for professional truck drivers, is that the five intervention domains comprised by the framework are not only applicable to safety, but to eco-efficiency as well. The latter for instance, can be derived from several (European) projects like Foot-LITE (see www.foot-lite.net), ECOWILL (www.ecodrive.org), GamECAR (www.gamecar.eu), ecoDRIVER (Saint Pierre et al., 2016), Ecomile (www.ecomilla.es), and eCoMove (www.ecomove-project.eu).

To illustrate, the eCoMove project in sub-project 4 'ecoFreight & Logistics' focused on companies transporting goods on the roads by means of heavy commercial vehicles, and ways to improve eco-efficiency. In Deliverable 4.1.(Krietsch et al., 2010) a functional architecture and system specifications were provided to describe the proposed intervention approach. The eCoMove system actually is an integrated solution composed of three applications: (1) ecoTourPlanning: this application allows a transport planner to determine the most fuel-efficient ecoTours for all vehicles based on a given set of transport order to fulfill, (2) Truck ecoNavigation: this application calculates the route to the next destination and guides the driver there. It considers the configuration/status of the vehicle and processes the necessary traffic status information to determine the most efficient route in terms of time and fuel, (3) ecoDriverCoaching: three components strive to achieve fuel efficiency in all trip phases: A driving simulator trains the driver in specific traffic situations (pre-trip); an on-board ecoDriver Coach supports the driver to drive in the most fuel-efficient way along the calculated route; an ecoFleet Business component in the backoffice provides post-trip analysis. The ecoDriverCoaching application was installed in a Volvo & DAF truck. From this illustration, it becomes clear that also in the case of eco-efficiency in an occupational context, the five intervention domains proposed by Mitchell et al. (2012), i.e. (1) management, systems & processes, (2) monitoring & assessment, (3) employee education & training, (4) vehicle technology, and (5) journey planning are all relevant.

In addition, focus is given on two out of the five basic intervention domains proposed by Mitchell et al. (2012), namely, domain two (i.e. monitoring & assessment), and domain three (i.e. employee education and training). The underlying motivation is that in light of the key-objectives set in the i-DREAMS project (i.e. to develop, implement, and test a platform that enables monitoring & assessment of driving behaviour [Project Pillar I], and to propose in-vehicle as well as post-trip interventions to promote a safe and eco-efficient driving style [Project Pillar II]), these two intervention domains are mostly relevant to further explore. More in particular, for each of these two domains, an overview of which intervention approaches or options have been described in the literature, is given.

2.4 Monitoring and assessment

As discussed in the previous section, performance monitoring and recognition is one key-domain for fleet safety managers to work on the improvement of road safety and eco-efficiency in an occupational context. According to Knipling (2009), 'Onboard Safety Monitoring (OBSM)' has several advantages over conventional safety measures among which: the fact that OBSM provides a 100% sample of driver behaviour, captures specific behaviours that cause crashes, incidents and violations, allows observation and rewarding of positive behaviours, makes negative behaviours can be seen and corrected before a crash, incident or violation occurs, allows driving behaviour-based benchmarks to be established so drivers know where they stand in relation to carrier expectations, and makes it possible to have frequent and timely evaluations, feedback, and consequences (including both rewards and punishments). Transport companies also monitor individual driver behaviour to follow up on fuel economy as a way to reduce costs. The use of OBSM increased substantially in the period where Behaviour Based Safety (BBS) became a popular paradigm in the domain of occupational health & safety. BBS is an approach where principles drawn from behavioural science are applied to the management of industrial safety. As explained by Krause et al. (1999) and Hickman et al. (2007), BBS tries to engage workers in improvement processes, teaches them to identify and observe critical safety behaviours, provides feedback to encourage improvement, and uses gathered data to target system factors for positive change. According to Knipling and Hyten (2010), the basic logic behind BBS can be visualized as in Figure 7 below.

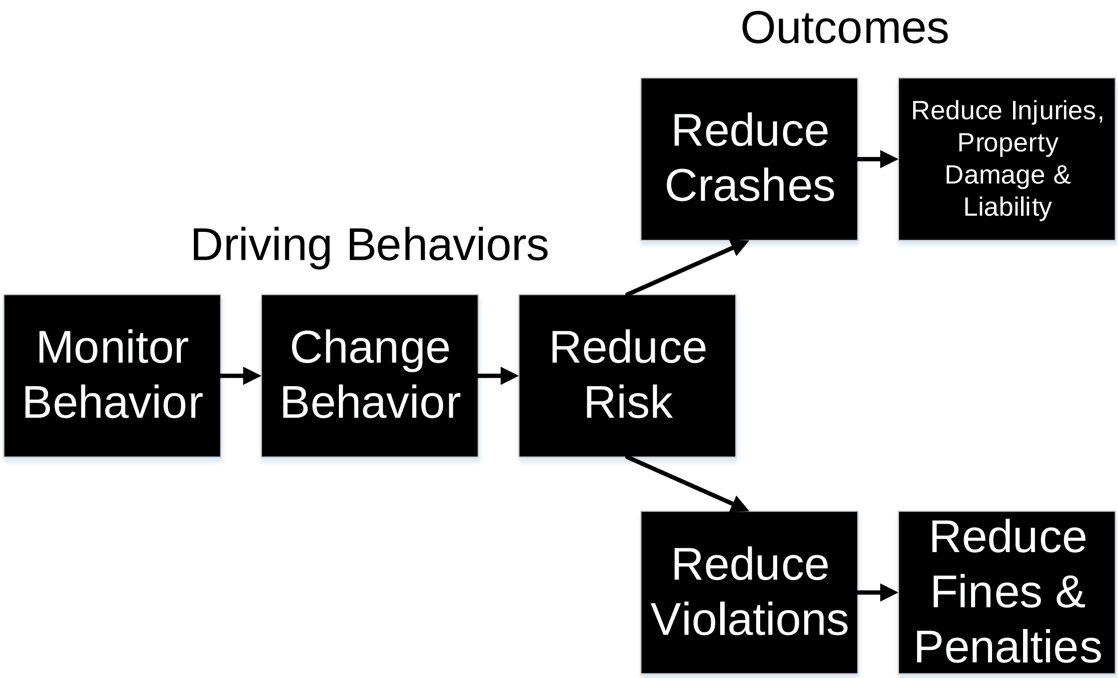

Figure 7: Behavioural model for reduction of crashes, violations, and associated consequences through behavioural monitoring and change. Source: Knipling and Hyten (2010)

To avoid misunderstanding, monitoring and recognition of performance in this section, refers to that specific intervention strategy where organizations make use of in-vehicle technologies to register, process, evaluate and change (if necessary) road safety and/or eco-efficiency, but in a *pre- or post-trip setting instead of in real-time while driving when it comes to evaluation and change.* More precisely, performance monitoring can be situated at two different levels. On the one hand, it can relate to parameters at the level of output indicators (for road safety, that could be for instance the number of (at-fault) accidents, or violations while for eco-efficiency that could be volume of fuel consumed, volume of greenhouse gases emitted, et cetera). On the other hand, performance monitoring can relate to behaviours contributing to those road safety- and eco-efficiency-related output indicators (e.g. speeding, harsh accelerations or decelerations, hard cornering, et cetera).

Below, Figure 8 pictures the overview of intervention approaches that were identified in the literature as appropriate in terms of performance monitoring and recognition. For a correct understanding of two things are to be noticed. Firstly, when ‘information’ or ‘feedback’ is used, the issuing of information or feedback is to be considered as falling outside the context of a trip (i.e. pre- or post-trip, not while driving). Secondly, in terms of *how* the information or feedback goes back to the targeted message recipient (depending on the situation, that can be the company owner, the fleet manager, the driver coach, or the truck operator), focus is given exclusively on technology-based media (e.g. app, website, e-mail) instead of face-to-face contact. In the proposed intervention taxonomy, performance-related information or feedback that is provided to message recipients in a face-to-face setting (e.g. a personal meeting with the driver coach, an in-company safety meeting, a moderated group discussion, a classroom session, et cetera), falls under intervention domain three, i.e. education and training (see subtitle ‘Employee education and training’). This does not imply that information or feedback delivered by technology cannot be used for educative or training purposes, but the intervention approaches falling under domain three in the proposed taxonomy always in one way or another require a form of human involvement, while this is not (necessarily) the case for the intervention approaches addressed here in domain two.

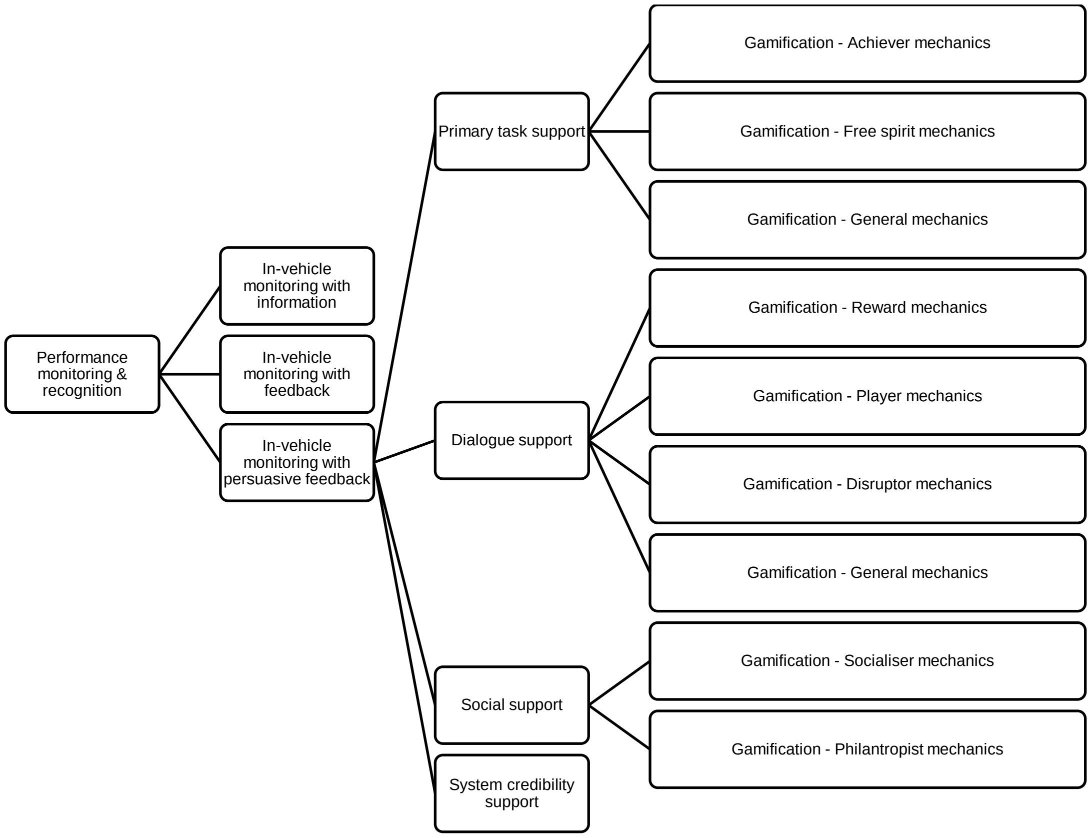

Figure 8: Overview of intervention approaches appropriate for domain 2 'Performance monitoring & recognition'

As can be derived from Figure 8, three intervention approaches related to performance monitoring and recognition can be found in the literature. These are in-vehicle monitoring with information, in-vehicle monitoring with feedback, and in-vehicle monitoring with persuasive feedback.

In-vehicle monitoring with information

The relevance of conceptually distinguishing between what is considered to be 'information' on the one hand, and 'feedback' on the other hand, has been clearly put forward in the MeBeSafe project. As pointed out by Karlsson et al. (2017: p.58), feedback is not only information, but also contains an evaluative dimension. Thus, receiving numbers on performance is information, while having them put into perspective (e.g., 'This is better than 60% of our drivers') is feedback." Over the years, several so-called critical use parameters (Bartholomew et al., 2016) have been identified in the literature that can have impact on the effectiveness of performance-related information as a behavioural change technique, even though the empirical evidence-base for these critical use parameters is not always robust nor consistent. Karlsson et al. (2017) mention the following information-related properties as potential determinants of impact :information quality (i.e. the credibility associated with the source of the information), information validity (i.e. whether information is objective or subjective), information complexity (i.e. the degree of difficulty), information detail (i.e. fine-grained vs. generic or general), information frequency (i.e. how often information is provided, like for instance, on a weekly basis or more/less frequently), information timing (i.e. while driving or pre/post-trip), and information control (i.e. whether issuing of information is use-driven (PULL) or system-driven (PUSH)).

Interestingly, attention in the organizational behaviour management literature for the use of information to increase safety-related work behaviours shifted towards the delivery of feedback (e.g. Fellner and Sulzer-Azaroff, 1984; Reber and Wallin, 1984; Ludwig and Geller, 1991, 1997; Williams and Geller, 2000; Hickman and Geller, 2003). Therefore, in-vehicle monitoring with feedback is the second intervention approach identified within the domain of driver monitoring and recognition.

In-vehicle monitoring with feedback

As already mentioned, information is not the same as feedback. As argued by Kluger and DeNisi (1996), Feedback Intervention Theory considers it to be a key-characteristic of feedback that it is not limited to a pure description of current performance. Instead, feedback also allows assessment of discrepancy between the current ‘actual’ state, and a desired performance or ‘ideal’ state. As contended in the literature on Goal Setting Theory (e.g. Tubbs, 1986; Wood et al., 1987; Locke & Latham, 1990, 2006), when the present state falls short of the hoped-for ideal state, a discrepancy is exposed. It is the discrepancy rather than the ideal state per se that has ‘corrective’ motivational properties. This corrective motivation can trigger different strategies to eliminate gaps between feedback received and the standard of comparison. A person can for instance be motivated to further pursue the desired state as a goal, to revise or change the desired state as a goal, to withdraw from the desired state as a goal, or to simply reject the received feedback. The standard of comparison can also be different. A person can compare feedback with a norm (e.g. personal performance relative to another person), a prior expectation, past performance levels, performance of other groups, an ideal goal, et cetera.

Al together, feedback can have three functionalities. When used informatively, feedback is meant to document progress towards goal attainment. When used instructively, feedback is meant to guide future goal setting efforts (i.e. the so-called ‘feed-up’ functionality), or to develop strategies to maximize goal achievement (i.e. the so-called ‘feed-forward’ functionality). Finally, as already explained, feedback can have a motivational purpose and act as a positive or negative reinforcer (e.g. further goal pursuit, revision and/or change of goal, goal abandonment, feedback denial or refusal).

Past research has identified critical parameters for the use of feedback as a behavioural change technique. To be mentioned here, is an interesting cycle of studies based on interviews and survey questionnaires targeting both truck operators as well as safety managers, where the focus was on opinions regarding the use of feedback to improve safe driving styles (Roetting et al., 2003; Huang et al., 2005; Zhang et al., 2006; Huang et al., 2008). The studies performed in the US showed that altogether, truck drivers reported they wanted to receive more feedback and that positive feedback was preferred over negative feedback. Feedback from supervisors or managers was more desired than feedback from technology. However, most drivers were willing to accept feedback from technology if properly designed. There was no particular preference as to timing, frequency and modality of delivery. Programs using feedback by technology should be adaptable to different driver preferences. Feedback was believed to improve safe driving performance and to defend drivers when involved in an accident. In general, comparable findings were obtained in China, although a few (cultural) differences emerged from the data. Chinese truck drivers were eager for more feedback about driving performance and willing to receive feedback from technology. Although negative feedback was prevalent in their working environment and considered as acceptable if it improves driving safety, positive feedback was considered as more helpful to safe driving. Feedback from technology was considered to be more objective and scientific than from humans. The majority of the respondents believed feedback would make them more safe drivers. Feedback-related concerns were about complexity, reliability and privacy. Preferably they receive feedback from driving partners or other truck drivers, but most preferred was feedback from technology. There was no particular preference in terms of feedback timing, frequency or modality.

In sum, besides the parameters associated with the use of information (i.e., quality, validity, complexity, detail, frequency, and timing), the effectiveness of feedback is potentially dependent upon (1) valence (i.e. positive vs. negative), (2) anchor (i.e. whether the standard of comparison is the self vs. others), (3) purpose (i.e. whether feedback is pedagogically aimed to teach or to direct), (4) relevance (i.e. personalized/context-specific vs. not personalized/context-specific), and (5) supervision (i.e. self-monitored vs. externally supervised).

Interest in the use of feedback to induce behavioural change has also received attention in the literature on eco-efficiency. Still recently for instance, Sanguinetti (2018: p. 3-7; 2019) proposed an integrative framework for the design of feedback, as shown in Figure 9.

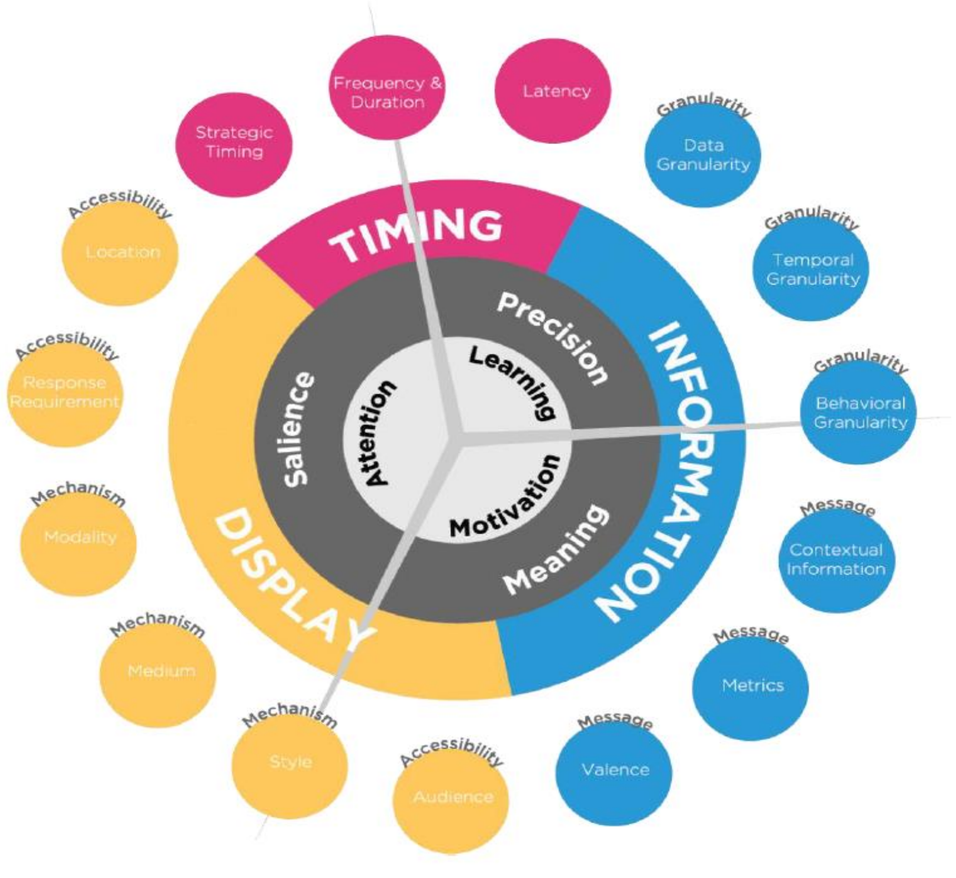

Figure 9: The Eco-feedback design-behaviour framework. Source: Sanguinetti (2018)

Summarized, the framework contends that for feedback to be effective, it should be salient (i.e. it must attract attention), precise (i.e. it should trigger a learning process), and meaningful (i.e. it should induce the appropriate motivation). These feedback functionalities are primarily dependent upon three specific design features, i.e. information, display, and timing.

As for the information presented, two particular aspects are important, namely message and granularity. More in detail, message-related components to consider are ‘metrics’ (i.e. the measurement units that are conveyed), ‘valence’ (i.e. the way measurements are framed), and ‘contextuality’ (i.e. the comparisons or the context-related information that is provided). As for metrics, Dogan et al. (2014) conducted a survey study where respondents received the monetary or carbon savings associated with several eco-driving scenarios, and were asked in which cases they would be motivated to modify their behaviour. It appeared the carbon saving-related metric was more persuasive than the monetary-related metric. As for the factor valence, a study by Rolim et al. (2016) where 40 drivers received delayed feedback (weekly e-mail report) on six eco-driving indicators over a three month period, established that negative feedback (performance decline from previous week) led to greater improvement in several of the eco-driving-related behaviours during the subsequent week, while the opposite happened with positive feedback. Although not related to eco-driving but to hazard perception, an interesting simulator experiment by Dogan et al. (2012) was also focused on how non-evaluative (but negatively experienced) feedback would impact people’s self-evaluation and performance. Actually it was found that neither performance nor self-evaluation changed. More in detail, the authors observed that members of the group who received non-evaluative feedback on their hazard perception performance, and learned accordingly that their estimated performance was lower than the actual performance, were more frustrated, had a more pronounced feeling of failure and were less satisfied with their performance. Regarding contextuality, Wada et al. (2011) showed it is more effective when standards of comparison are adaptive in a sense that performance bars should raise when driver skill levels increase.

Relevant display dimensions are accessibility and the presentation mechanism used. Relevant accessibility-related aspects are ‘audience’ (i.e. who can access?), ‘location’ (i.e. where can it be accessed?) and ‘response requirement’ (i.e. how is it accessed?). To date however, no work has been done where the effect of feedback accessibility on eco-driving has been empirically investigated. The situation is different for aspects related to the presentation mechanism used. According to the Eco-feedback Design Framework, three presentation-related factors are to be taken into account: modality (i.e. the sensory mode of the interface), style (i.e. the look/sound/feel of messages provided), and medium (i.e. the physical origin of feedback). Various experimental studies already compared different (combinations) of feedback modalities (e.g. Azzi et al., 2011; Staubach et al., 2014; Hibberd et al., 2015; Jamson et al., 2015; Hammerschmidt and Hermann, 2017; McIlroy et al., 2017). In general, results are mixed and inconclusive. Yet, it seems that visual feedback may be less effective than auditory- or vibrotactile (haptic) feedback, the latter especially effective for alerts, but not for more complex direction cues (see Prewett et al., 2012). Furthermore, empirical research seems to support the idea that different modalities combined (i.e. multi-sensory feedback) is more effective than a single modality (e.g. Ho and Spence, 2008). As for feedback style, in the auditory modality, a guzzling sound was more effective than a constant noise signal in a study on the use of engine speed and eco-efficiency (Hammerschmidt and Hermann, 2017). In the haptic modality, Jamson et al. (2015) and Jamson et al. (2015) both demonstrated that force pedal feedback was better performing than a stiffness pedal feedback. Opposite results however were reported by Mulder et al. (2008). As for the factor medium, Riener et al. (2010)

observed that vibrating seat belts was more effective than vibration seats for the improvement of fuel efficient driving.

Finally, the Eco-feedback Design Framework contends that timing-related properties are to be taken into account. The relevant properties are ‘latency’ (i.e. length of time-gap between relevant behaviour and presentation of feedback), ‘frequency and duration’ (i.e. how often feedback is presented or updated and for how long), and ‘strategic timing’ (i.e. at what specific time feedback is presented or updated). While Kircher et al. (2014) showed that intermittent visual feedback performed better than continuous visual feedback (lower dwelling times were observed for the former), Fors et al. (2015) found drivers to perform better with continuous visual feedback on coasting, than with intermittent visual feedback, albeit differences were not statistically significant. In their simulator experiment, Donmez et al. (2008) were not focusing on eco-driving, but on distraction mitigation feedback, and they found that the combination of concurrent feedback (i.e. feedback provided in real-time) and retrospective feedback (i.e. feedback presented at the end of a trip) was most promising. Comparable findings were reported by Molloy et al. (2019) in a study on feedback-based strategies to improve young drivers’ speed management. The authors found that combined feedback (i.e. an auditory signal for exceeding the posted speed limit while driving, in combination with post-trip feedback on number of times the speed limit was exceeded, the associated financial penalties, and the safety implications) was most effective in reducing the average speed, and the percentage of time speeding in both low-speed (50km/h) and high-speed (80km/h) zones. Another study by Levi-Bliech et al. (2019) examined the effectiveness of a fleet management app, providing drivers with feedback about their driving before their next drive (i.e. pre-trip setting) in combination with real-time notifications while driving. The hypothesis that pre-trip feedback would reduce risky driving behaviour and that this association would be mitigated by real-time notifications and enhanced by experience with the app, was supported. Slightly different findings were reported in a study on the impact of immediate or delayed feedback on driving behaviour in a simulated Pay-As-You-Drive system by Dijksterhuis et al. (2015). They compared the effectiveness of immediate vs. delayed feedback and found that there was a moderate advantage of using immediate in-car feedback over delayed feedback via a website.

Based on a very comprehensive literature review (see Sanguinetti et al., 2017; Sanguinetti et al., 2017; Sanguinetti et al., 2018), Sanguinetti (2018) came to the following main conclusions regarding the effectiveness of feedback to promote an co-efficient driving style. First of all, conveying information about fuel efficiency to the driver seems to be the most common strategy to promote eco-driving, with feedback typically provided onboard the vehicle via digital screens like dash or cluster displays, after-market devices or web apps on personal smartphones or tablets. Secondly, despite the fact that the literature generally suggests that feedback can be effective in promoting eco-driving, results vary considerably which is likely due to study differences in terms of feedback design, sample characteristics, study setting, length of intervention, et cetera.

Interestingly, Sanguinetti (2018) also conducted a meta-analysis to formally test a set of fourteen hypotheses about the characteristics and contexts that can have impact on the effectiveness of feedback. All of these were supported by behavioural theory and past empirical research. In total the meta-analysis was based on a sample of 23 effects reported in 17 different studies. It came out that the main effect of on-board feedback on fuel economy was a 6.6% improvement whereas the average fuel economy without feedback in these studies (i.e. in the baseline phase or in control groups) was about 25 Miles Per Gallon (MPG). Consequently, a 6.6% improvement from that baseline or control, would equal to a 1.7 MPG improvement. Only one out of the fourteen hypotheses could be supported in a statistically significant way, i.e. the negative relationship between length of intervention (i.e. number of days drivers were exposed to feedback) and feedback effectiveness. In other words, the effect of feedback decreased as length of intervention increased. According to the author, lack of statistically significant support for the other hypotheses focusing on feedback design and context variables was likely related to small sample sizes. Notwithstanding, trends could be identified that aligned with the forwarded hypotheses, suggesting that feedback should best (1) be provided in multiple modalities, (2) include both fine- and course-grained information, (3) provide standards of performance comparison, (4) integrate game features (like points, levels or badges), and (5) be combined with other behavioural change techniques such as education and/or rewards contingent on performance (see Sanguinetti, 2018).

Even though all of the above mentioned design features are relevant to consider when using feedback as a behavioural change technique, several authors have contended that for feedback to be effective, it is primarily important that feedback serves additional functionalities (i.e. feed-up, feed-forward, corrective motivation) on top of serving a purely informative purpose. Goals or feedback alone not necessarily activate the required self-regulatory processes targeted to realize the desired behavioural change (e.g., Bandura & Cervone, 1983; Cervone and Wood, 1995; Kluger and DeNisi, 1996; Hickman and Hanowski, 2011). This is one of the main reasons why at some point in time, the concept of ‘persuasive’ feedback was forwarded in the literature on technology-mediated behavioural change (see for instance Fogg, 1998, 2009a, b, 2010). In-vehicle monitoring with persuasive feedback is the third intervention approach identified within the domain of driver monitoring and recognition.

<u>In-vehicle monitoring with persuasive feedback</u>

At the end of the nineties, Brian Fogg introduced a new field of scientific inquiry, for which he coined the term ‘captology’ (Fogg, 1998). It is an acronym for ‘computers as persuasive technology’ and refers to the study of technology (e.g. interactive information technology like the Web, Internet, mobile- and other ambient technologies) to influence attitudes and behaviour. More in detail, persuasive systems can be defined as “computerized software or information systems designed to reinforce, change or shape attitudes or behaviors or both without using coercion or deception” (Oinas-Kukkonen and Harjumaa, 2008).

In order for technology to be able to change user behaviour successfully, Fogg (2009b) posits that three ingredients are required. The technology should improve the ability of the user to perform the targeted behaviour, stimulate the motivation to perform the targeted behaviour, and trigger elicitation of the targeted behaviour at the appropriate time and context. Together, ability, motivation and triggers constitute the basic pillars of the Fogg Behavioural Model (FBM), which serves as a popular theoretical blueprint in the field of technology-mediated behavioural change. As discussed in a very interesting theory building article by van Gent et al. (2019), later work on the design of persuasive systems by Oinas-Kukkonen and Harjumaa (2009) integrated the principles underlying the FBM with two other major paradigms on behavioural change, i.e. Behavioural Economics and Gamification.

The basic tenet behind Behavioural Economics is that humans are not always perfectly rational in the way they make judgments and take decisions in everyday life (e.g., Ariely, 2009, 2010; Glimcher and Fehr, 2014; Raue et al., 2018). Rather, they often are guided by so-called heuristics (mental shortcuts), especially in situations where the opportunity to reflect is limited, and where available information or options to assess, are ambiguous or complex and future outcomes are uncertain or difficult to predict (e.g. Chaiken and Trope, 1999; Strack and Deutsch, 2004; Kahneman, 2013). It also very well known that humans are (unconsciously) sensitive to social settings when they have to take behaviour-related decisions (for a review of work on implicit social cognition, see Gawronski and Payne, 2010). Insights from Behavioural Economics led scholars to innovative approaches in terms of behavioural change, the most popular one probably being the so-called Nudging approach (see Thaler and Sunstein, 2009). As highlighted by van Gent et al. (2019: p. 206), principles derived from Behavioural Economics and Nudging strategies have also been applied in the field transportation, such as to the design of travel information systems (Avineri, 2011), the promotion of safe driving behaviours (Millar and Millar, 2000; Mortimer et al., 2018), and methods for the analysis of travel behaviour (Metcalfe and Dolan, 2012).

2.5 Legal framework for professional drivers

The first directives regarding the training of professional drivers were laid down already in 1976 ("Council Directive 76/914/EEC"), which were afterwards amended and/or repealed in 1985 ("Council regulation EEC No 3820/85") and in 2003. Before the introduction of Directive 2003/59/EC, professional driver qualification schemes played a rather subordinate role in most European countries in terms of availability and impact. The overall situation was characterized by very limited availability and access to training, and the percentage of drivers attending training ranged far below the overall percentage in Europe (for instance the ProfDRV project: www.project-profdrv.eu). The prevailing attitude appeared to be that professional competence was to be acquired 'on-the-job'. Directive 2003/59/EC was precisely aimed at addressing this situation, and laid down so-called 'minimum requirements' for initial qualification and periodic training for professional drivers of trucks and buses. Besides, in 2006 the directives regarding the rules on driving licences (for different categories of power-driven vehicles) were finalized in "Directive 2006/126/EC".

In 2010-2011 the political sense of urgency for increased efforts to improve road safety and to decrease the ecological footprint of transportation received a new impulse, as can be derived from a set of crucial vision papers set out by the European Commission: "Communication Towards a European road safety area: policy orientations on road safety 2011-2020 (COM 2010-389)" and "Communication: the Europe 2020 strategy for smart, sustainable and inclusive growth (COM 2010-2020)" in 2010, and the "Transport White Paper (Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system) (COM 2011-144)" in 2011. Furthermore, several studies were performed by relevant stakeholder groups about the existing legislative framework on driving licences and training of professional drivers. These studies included for instance the "ProfDRV-project on the implementation of Directive 2003/59/EC" in 2010-2013 (www.project-profdrv.eu), the "Report on the implementation of Directive 2003/59/EC" in 2012, the "Report of the High Level Group on the Development of the EU Road haulage Market" in 2012, the "Survey on driver training issues" by ETF & IRU in 2013, a CPC Workshop organized by CIECA in 2013, and the "Ex-post evaluation study on the effectiveness & improvement of the EU legislative framework on training of professional drivers" by Panteia in 2014. The combination of these vision papers and the performed studies led to the conclusion that there were some areas of improvement and a few inconsistencies identified in the existing Directives. The most important findings were: a large heterogeneity in the training approaches (initial qualification and periodic training requirements) in the different Member States, and insufficient attention for some ongoing developments in the truck sector (e.g. new vehicle technologies).

These findings led in 2017 to the proposal for a Directive of the European Parliament and of the Council amending Directive 2003/59/EC on the initial qualification and periodic training of drivers of certain road vehicles for the carriage of goods or passengers and Directive 2006/126/EC on driving licences, which was finally laid down in 2018 in the “Directive 2018/645”.

2.5.1 Legislation framework for trucks

In this section, focus is given on the legal framework that determines what the minimum requirements are for persons to comply with in order to be able obtain a category C licence, and to be allowed to operate a truck as the primary professional activity. Driver licence-related requirements are set by Directive 2006/126/EC and minimum requirements for initial qualification and periodic training of professional drivers are captured by Directive 2003/59/EC. Both Directives have recently been amended by Directive 2018/645. In what follows, the pathway that led to Directive 2018/645 is sketched (in the section "Background", as shown below). Afterwards, focus is given on the three Directives themselves, and a comparative overview of the different requirements to which professional truck drivers need to comply is provided. An overview of minimum requirements is also provided. Appendix A gives a detailed overview of the requirements laid down in the three Directives mentioned above.

Therefore, the current legal framework of the European guidelines for professional truck drivers, which are binding for all Member States, consists of three Directives. The first Directive, “Directive 2006/126/EC of the European Parliament and of the Council of 20 December 2006 on driving licences (Recast)”, consists of the rules on driving licenses, i.e. defining the knowledge (theory test), skills and behaviour (test of skills and behaviour) connected with driving motor vehicles. The second Directive, “Directive 2003/59/EC of the European Parliament and of the Council of 15 July 2003 on the initial qualification and periodic training of drivers of certain road vehicles for the carriage of goods or passengers, amending Council Regulation (EEC) No 3820/85 and Council Directive 91/439/EEC and repealing Council Directive 76/914/EEC”, lays down the initial qualification and periodic training requirements for professional truck drivers. This Directive includes both the requirements of the qualification and training systems, as well as how drivers can be issued with a certificate of professional competence (CPC). The third Directive, “Directive (EU) 2018/645 of the European Parliament and of the Council of 18 April 2018 amending Directive 2003/59/EC on the initial qualification and periodic training of drivers of certain road vehicles for the carriage of goods or passengers and Directive 2006/126/EC on driving licences”, consists of the recent amendments of Directives 2003/59/EC and 2006/126/EC. The table in Appendix 1 gives an overview of the most relevant information of the three Directives.

The analysis of the European guidelines shows that there are different knowledge, skills, competences and behavioural aspects that professional truck drivers should fulfill. Regarding knowledge aspects, according to “Directive 2006/126/EC”, the driver should have the required general knowledge similar to all other vehicle categories, about road traffic regulations; the driver; the road; other road users; general rules and regulations and other matters; precautions necessary when alighting from the vehicle; mechanical aspects with a bearing on road safety; vehicle safety equipment and, in particular, the use of seat-belts, head restraints and child safety equipment; and rules regarding vehicle use in relation to the environment. Besides, he/she should also have general knowledge about driving with trucks: about rules on driving hours and rest periods, vehicle weights and dimensions, the type of transport concerned; required vehicle and transport documents; accident handling; precautions during removal/replacement of wheels; obstruction of the field of view; reading road maps; and safety factors relating to vehicle loading. Additionally, the driver should have general additional knowledge about driving with trucks with a maximum authorized mass exceeding 7500kg: principles of construction and functioning; lubrication and antifreeze protection; principles of construction/ fitting/use/care of tyres, brake fittings and speed governors; methods of locating causes of breakdown; preventive maintenance of vehicles and running repairs; and responsibility in respect of the receipt/carriage/delivery of goods.

According to “Directive 2003/59/EC”, the driver should have a minimum level of knowledge not less than level 2 of the training-level structure provided for in Annex A to Decision 85/368/EEC; amended to a minimum level of qualification comparable at least to level 2 of European Qualifications Framework as provided for in Annex A to Recommendation of the European Parliament and of the Council of 23 April 2008 in “Directive 2018/645”. The list of subjects includes rational driving based on safety regulations: to know the characteristics of the transmission system, to know technical characteristics and operation of the safety controls (amended: including the use of electronic and mechanical devices approved for use, driver assistance or automation devices); application of regulations: to know the social environment of road transport and the rules governing it (amended: principles, application and consequences of Regulations (EC) No 561/2006 and (EU) No 165/2014), to know the regulations governing the carriage of goods (amended: including documents to be carried in the vehicle, bans on using certain roads, road-use fees, obligations under standard contracts for the carriage of goods); and health, road and environmental safety, service and logistics: awareness of risks of the road and of accidents at work, to know the economic environment of road haulage and organisation of market (amended: including different transport specialisations (dangerous goods, animal transport)).

Regarding skills and behaviour, according to “Directive 2006/126/EC”, the requirements relate to the preparation and technical check of the vehicle with a bearing on road safety (capable of preparing to drive safely), special manoeuvres with a bearing on road safety (reversing along a curve, parking safely for loading/unloading), and behaviour in traffic (driving away, crossroads, changing direction, etc.). The driver should show a defensive and social driving behaviour, including adapted and determined (safe) driving, taking into account road and weather conditions, other traffic, the interests of other road users (particularly more vulnerable) and anticipation. According to “Directive 2003/59/EC”, the driver should have the necessary skills and behaviour related to rational driving based on safety regulations: ability to optimize fuel consumption (amended: including importance of anticipating traffic flow, appropriate distance to other vehicles, improving the driving efficiency), amended: ability to anticipate, assess and adapt to risks in traffic, and ability to load the vehicle with due regard for safety rules & proper vehicle use (amended: including use of automatic transmission systems). Regarding health, road and environmental safety, service, logistics, the driver should have the ability to prevent criminality and trafficking in illegal immigrants, the ability to prevent physical risks, awareness of the importance of physical and mental ability, ability to assess emergency situations, and ability to adopt behaviour to help enhance the image of the company.

Concluded, the legal framework for professional truck drivers shows that the minimum requirements (knowledge, skills and behaviour) in general relate to both improving the safety and improving the eco-efficiency. This is closely relates to the ‘smart’ driving principle of Young et al. (2011), meaning that the driving of (professional) truck operators should be both safe and green (i.e., eco-efficient).

2.5.2 Legislation framework for buses

Many vehicle safety requirements, namely the incorporation of ADAS systems, were established as a mandatory requirement for type approval and new vehicles by the General Safety Regulation (EC) No 661/2009 and Pedestrian Safety Regulation (EC) No 78/2009. The General Safety Regulation (GSR) introduces as mandatory, for specific types of vehicles, the deployment of advanced driver assistance systems such as Stability Control (ESC), Advanced Emergency Braking (AEB), mandatory from November 2015 onwards for all new buses and trucks, and Lane Departure Warning (LDW), mandatory for all new trucks and buses from November 2015 onwards, on all new trucks and buses. On its turn the Pedestrian Safety Regulation (PSR) introduced as mandatory the Emergency Brake Assist (EBA). Although some of the measures are still being phased in until 2023 most are now standard on new vehicles.

Following extensive research data and recommendations provided by EU commissioned studies, the European Commission revised the General and Pedestrian Safety Regulations. These then led to new regulations that provide a mandatory character for the deployment of certain ADAS systems for the different vehicle types. For cars, vans, trucks and buses the new regulations impose as type-approval requirements the existence of driver drowsiness and distraction systems (e.g. smartphone use while driving), intelligent speed assistance, reversing safety with camera or sensors, and data recorder in case of an accident (‘black box'). Furthermore, for trucks and buses, specific requirements are imposed in order to improve the direct vision of bus and truck drivers and to remove blind spots, assisting drivers to detect vulnerable road users, at the front and side of the vehicle, especially when making turns.

In particular, for the case of buses the new safety regulations address the following systems:

- Alcohol Interlock installation facilitation
    - From September 2020 onwards approval type requires the facilitation for the installation of Alcohol Interlock Device Installation for all M and N vehicles. All new vehicles registered from September 2022 must comply with this requirement.
- Drowsiness and Attention Detection, Distraction Recognition and Prevention
    - The regulation is technology neutral and mandatory for all vehicles from M and N categories. Its application date is coupled with AEB and LKA systems.
- Event (Crash) Data Recorder
- Emergency Stop Signal
    - Emergency braking display, in compliance with UNECE regulations R13, R13-H and R38 becomes mandatory for all M and N vehicles, starting in September 2020 for new type approvals and two years later for all registered new vehicles.
- Intelligent Speed Assistance
    - Current technology to be based on TSR systems with future system to extend it functionality to integrate with V2I communication and digital mapping.
    - It will become mandatory for all type approvals on the 1st of September of 2022 and four years later to all registered new vehicles.
- Reversing Camera or Detection systems
    - Under the new safety regulations, reversing object detection becomes mandatory for all M, N and O vehicles type-approvals from 2020 onwards and two years later for all new registered vehicles.

- Tire Pressure Monitoring Systems
    - The installation of TPMS for becomes mandatory for all M, N and O vehicle type-approval from 2020 onwards and for all registered new vehicles after September 2020.
- Detection of Vulnerable Road Users and Warning on front and side of vehicle
- Safety-Belt Reminder
    - For M2 and M3 category buses the seat-belt reminder for all front seats became mandatory for type-approval in September 2018 and for all registered new vehicles in September 2020.

A list of relevant requirements, respective regulations and application dates relevant for bus road safety are summarised in the Table 1 below.

Table 1: Overview of relevant requirements, respective regulations and application dates relevant for bus road safety

Subject	UN Regulations	Additional Specific Technical Requirements	M2	M3
Pedestrian and cyclist collision warning			B	B
Blind Spot Information System			B	B
HDV direct vision			D	D
Indirect Vision	UN Reg. No 46		A	A
Reversing Safety			B	B
Lane Departure Warning			A	A
Stability control	UN Reg. No 13 UN Reg. No 140		A	A
Advanced Emergency Braking on HDV	UN Reg. No 131		A	A
Tyre pressure monitoring for HDV			B	B
Audible warning	UN Reg. No 28		A	A
Intelligent Speed Assist			B	B
Emergency Stop Signal			B	B
Alcohol interlock installation facilitation			B	B
Drowsiness and attention detection			B	B
Advanced distraction recognition		Advanced distraction recognition may also cover drowsiness and attention detection. Distraction avoidance by technical means may also be taken into consideration as an alternative to advanced distractions recognition	C	C
Driver availability monitoring			B	B

Event (accident) data recorder			B	B
Systems to provide the vehicle with information on state of vehicle and surrounding area			B	B
Platooning			B	B

A: Carried over from current GSR, PSR or HSR, applies as from 3 years after adoption, i.e. immediately upon date of application, for all new vehicles

B: New requirement, applies as from 3 years after adoption for new types and as from 5 years for all new vehicles

C: New requirement, applies as from 5 years / 7 years after adoption

D: New requirement, applies as from 7 years / 10 years after adoption

As previously mentioned, the most common advanced driver-assistance safety critical systems that provide real-time information to the driver are provided as standard or optional equipment by OEM. Despite the ever increasing number of safety assistance systems mandatory for new type approvals, within the UE, the extended life-cycle of heavy duty vehicles implies that most system now deemed as essential by the UE, and enforced by the new GSR and PSR, will only be ubiquitous across the global bus and coach fleets in 15 or 20 years from now. To overcome this gap several commercial aftermarket solutions have been developed, either by OEM themselves or by third-party suppliers. When retrofitted into existing vehicles, these aftermarket solutions offer them some of the safety assistance features the UE assess as safety critical, so that they must become standard for heavy duty vehicles in general and buses in particular. However, due to the complexity of related homologation processes for active systems and often unavailability of driver-independent actuators control, the aftermarket solutions are frequently limited to passive solutions that evaluate the road context and driver behaviour to assess risk and warn the driver accordingly by means of visual, audible and haptic feedback/interventions or ever so often focused solely in efficient driving.

Additionally, one may distinguish two types of systems according to the data used when assessing safe and efficient driving behaviours. On the one hand there are systems that rely solely on data collected by sensors external to the vehicles, namely GPS data, accelerometers and other inertial sensors and, eventually, cameras. On the other hand, plenty aftermarket systems, including the ones provided by the OEM, often combine, i.e. fuse, vehicle data with additional external sensors. In such systems, the vehicle data is fed by one or multiple vehicle CAN buses, usually using either FMS or OBD II standard interfaces, based on the standard SAE J1939 communication protocol for heavy-duty vehicles.

FMS standard was recently reviewed and, unlike the first releases, its version 04 increasingly harmonizes Fleet Managing Service communication standard for buses and trucks. This harmonization has been promoting an ever wider integration and standardization of telematics and driver monitoring solutions for heavy-duty vehicles. That combined with a much larger truck market, often operating in extremely competitive business segments, means that most systems are initially conceived for trucks and only then extended or adapted to the bus market. The FMS gateway provides, according to SAE J1939, the following parameters:

Shared Variables:

- Fuel Consumption: LFC
- Dash Display 1: DD1
- Electronic Engine Controller #1: EEC
- Engine Hours, Revolutions: HOURS
- Vehicle Identification: VI

- FMS-standard Interface Identity / Capabilities: FMS
- High Resolution Vehicle Distance: VDHR 16
- Tachograph: TCO1
- Engine Temperature 1: ET1
- Ambient Conditions: AMB
- Driver's Identification: DI
- Fuel Economy: LFE
- Air Supply Pressure: AIR1
- High Resolution Fuel Consumption (Liquid): HRLFC
- After treatment 1 Diesel Exhaust Fluid Tank 1 Information: AT1T1I
- FMS Tell Tale Status: FMS1
- Electronic Brake Controller 1: EBC1
- Electronic Engine Controller 14: EEC14
- Fuel Consumption (Gaseous): GFC
- Electronic Retarder Controller 1: ERC1
- Time / Date: TD
- Alternator Speed: AS
- Electronic Transmission Controller 2: ETC2
- Air Suspension Control 4: ASC4
- Vehicle Electrical Power #4 : VEP4
- Vehicle Dynamic Stability Control 2 : VDC2

Bus Specific

- Cruise Control/Vehicle Speed: CCVS
- Electronic Engine Controller #2: EEC2
- Door Control 1: DC1
- Door Control 2: DC2

Truck Specific

- Cruise Control/Vehicle Speed 1: CCVS1
- Electronic Engine Controller #2: EEC2
- Vehicle Weight: VW
- Service Information: SERV
- PTO Drive Engagement: PTODE
- Combination Vehicle Weight: CVW

These parameters, conveyed by FMS data, allow for vehicle and driver automatic identification, as well as monitor driving time and key performance indicators, which can be combined with computer vision, GPS and inertial data to deliver accurate in-depth driving behaviour analysis and real-time feedback for continuous driving style, safety and efficiency improvements. The market offers already a vast array of solutions that provide driver assistance however most fail to take into account the human factor, namely the different drivers' preferences and respective momentaneous status, into the assistance, leading to reduced acceptance or low continued engagement. In the present context of i-DREAMS, before addressing potential integration into OEM assistance systems, it is key to identify key suppliers and solutions with real-time driver support and coaching, with particular emphasis on aftermarket or integration proposals, to understand their respective feedback strategies and the added gains that could result from taking into account the human factors.

2.6 Employee education and training

Heavy vehicle driver education and training has a longstanding tradition (Brock et al., 2007). In the fleet safety management literature focusing on truck operators, some of the earliest applications go back already to the sixties, mainly coming from the United States. Payne and Barmack (1963) for instance, examined the effectiveness of a training format that was referred to as the Smith-Cummins-Sherman (SCS) method. The SCS method focused on the development of systematic perceptual search habits to detect driving hazards, and using the appropriate driving strategies to dispose of these hazards before becoming critical. In a study with 120 professional drivers in a truck company, Payne and Barmack (1963) found that an SCS-method based training taught by a particular instructor had a subsequent accident history that was significantly lower than the accident rates of drivers taught by other instructors and those who were in the control group. Although some considered this to suggest that SCS-training was a potentially promising way to improve occupational road safety, others were rather skeptical. For example, both and OECD expert group (OECD, 1970) and Saffron (1981) came to the conclusion that the results obtained by Payne & Barmack were probably more related to the personality of the trainer than to the method employed. In other words, the instructor was considered to be more important than the instruction method itself.

The so-called ‘defensive driving courses’ for commercial heavy vehicle drivers were another popular training format. Based on a review of early studies in America where the effectiveness of this specific method was investigated, Coppin (1977) concluded that, rather than defensive driver training, rigorous employee selection criteria instituted by management (resulting in developing a pool of an older and more experienced group of drivers) were primarily responsible for observed decreases in accident rates over longer time periods. Sandow (1979) came to comparable conclusions based on study work in Australia.

According to Henderson (1991), the above referred to cases were exemplar illustrations of what he considered to be a striking feature of the literature on heavy vehicle education and training at that point in time, namely: “the lack of hard evidence on the effectiveness of truck driver training during the last decade, compared to the almost universal support for its application and extension.” (Henderson, 1991: p. 38). Henderson indeed had a point. Intuitively, education and training has strong appeal in the eyes of many stakeholders, among which policy makers, company owners, fleet safety managers, professional coaches and instructors, as well as truck operators themselves. The latter can be derived from a widespread number of policy documents, fleet safety manuals, company guidelines, opinion pieces, audit materials, such as the Fleet Safety Manual (Federal Office of Road Safety, 1995), the Motor Fleet Safety Manual (Brodbeck, 1996), UK guidelines as proposed by the Royal Society for the Prevention of Accidents (2003), the Safe Practices for Motor Vehicle Operations (American Society of Safety Engineers, 2006), the Safer Motoring How to Guide (Australasian Fleet Managers Association, 2008), or the Fleet Safety Guide (Fleet Forum, 2009). The popularity of employee education and training can also be inferred from several of the CTBSSP synthesis reports (e.g. Knipling et al., 2003; Brock et al., 2007; Knipling et al., 2011).

Cavallo (1987), strictly taken acknowledges the potential of professional driver education and training to contribute to occupational read safety. However, according to the author, in order for that potential to realize, safety oriented training programs would have to be able to (1) reduce the time and increase the probability of acquiring skills associated with lower accidents risks, and (2) improve on the optimum level of accident free driving now attainable, either by developing safety skills already attainable through developing extra safety skills. Importantly, Henderson (1991: p. 38) points out that the two requirements mentioned by Cavallo (1987) are actually dependent on the quality of training courses, and there is a need to investigate the process and development of particular driver qualities in order to determine whether they may be instilled through training. However, present courses of instruction are based only on the judgement and experience of experts in the field rather than on scientific research."

The least one can say is that the evidence-based effectiveness of professional driver education and training is a controversial topic. Over the years, education- and training approaches have proliferated with all sorts of pedagogical and didactical formats, methods and materials developed and described in the literature. In Europe, these were boosted by Directive 2003/59/EC, imposing a Certificate of Professional Competence on professional drivers, for which the minimum requirements foresee an initial qualification and periodic training. The main purpose of this section is to describe and bring together these different approaches into one overall taxonomy of employee education and training techniques.

As will become clear, a basic distinction can be made between theory-based approaches and practice-based approaches. Within these two basic approaches, a further distinction is made in function of the Learning Styles Model as it was proposed by David Kolb (1984). This model has also been referred to as Kolb's Experiential Learning Theory (ELT) or as Kolb's Learning Styles Inventory (LSI) and is based on the idea that learning actually is a sort of cyclical process consisting of four stages that builds upon four different learning styles. Thus, Kolb's model works at two levels, i.e. a four stage cycle (i.e. concrete experience, reflective observation, abstract conceptualization, and active experimentation), and a four-type definition of learning styles (i.e. diverging, assimilating, converging, and accommodating). Figure 10 visualizes how the idea of a four-stage learning cycle and four different learning styles come together in Kolb's Learning Styles Model.

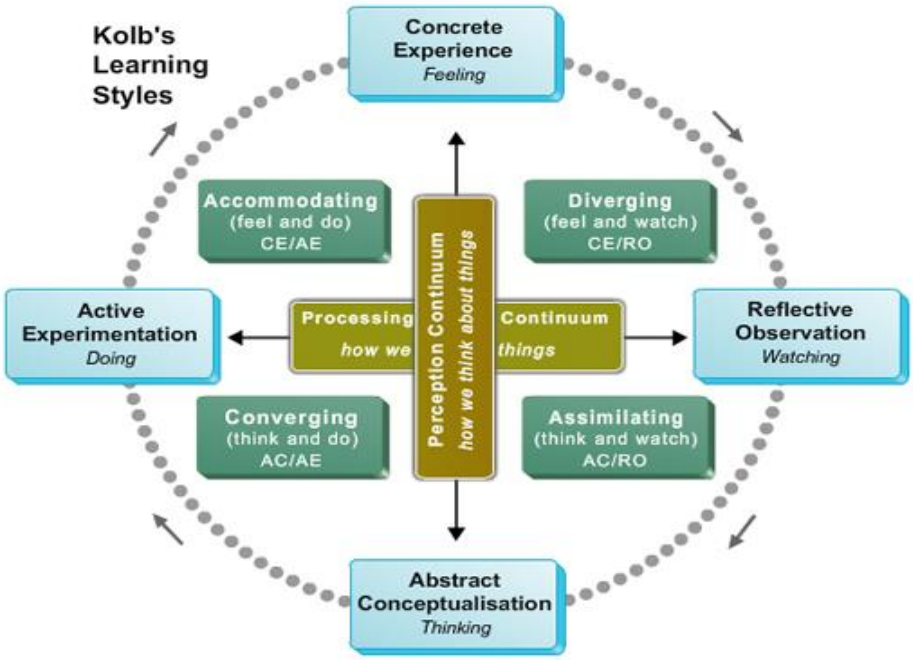

Figure 10: Kolb's Learning Styles Model. Source: www.ruspat.wordpress.com

As can be derived from Figure 10, the four learning styles in the model are the combination of two different continuums. On the one hand, (horizontal) Processing Continuum stands for how people approach a task or how they 'grasp experience' (i.e. doing or watching), while (vertical) Perception Continuum represents how people 'transform experience' (i.e. feeling or thinking). Depending on what position is taken on these two continuums, four different learning styles can be distinguished.

- A learning style qualified as 'diverging' is characterized by a watching position on the Processing Continuum and a feeling position on the Perception Continuum. A diverging learning style is typically relevant in situations where immediate or concrete experiences (feeling) provide a basis for observations and reflections (watching).
- An 'assimilating' learning style is characteristic for a watching position on the Processing Continuum in combination with a thinking position on the Perception Continuum. Assimilation is a relevant learning style in settings where observations and reflections (watching) are further processed and distilled into abstract concepts (thinking).
- A 'converging' learning style combines a doing position on the Processing Continuum with a thinking position on the Perception Continuum and is most applicable to situations where abstract concepts (thinking) are producing new implications for action which can be tested (doing).
- An 'accommodating' learning style implies a doing position on the Processing Continuum together with a feeling position on the Perception Continuum, and fits with a context where actively tested abstract concepts (doing) enable the creation of new experiences (feeling).

According to Kolb, ideally the learning process is a cycle or spiral where concrete experiences lead to reflective observation, which then result in abstract conceptualization in order to allow active experimentation to end in new concrete experiences. Evidently, this is not always the case, and people can step into the learning cycle at any of the four stages, depending on the circumstances. For example, a person soliciting for education or training in the context of initial qualification will not necessarily yet have a lot of concrete experiences to start from while an experienced professional driver following periodic training to get a 'code 95' will have an elaborate repertoire of concrete experiences to bring in. As already mentioned, in the field of (professional) driver education and training, a traditional distinction is made between theory-based methods on the one hand, and practice-based methods on the other hand. In light of Kolb's Learning Styles Model, it is reasonable to argue that overall, theory-based methods lend themselves best to a diverging learning style and/or an assimilating learning style. Indeed, theoretical sessions are often aimed at stimulating people to observe and reflect on their own concrete experience, or that of others (i.e. divergence), and to use these observations and reflections to lead to new insights on how to improve (i.e. assimilation). In other words, the theory-based approach in education and training of (professional) drivers often uses concrete experiences as a starting point to initiate a learning cycle, but primarily target the reflective observation stage and the abstract conceptualization stage. Different from that, the practice-based approach primarily aims to stimulate convergence (i.e. putting into practice new insights for improvement) and/or accommodation (i.e. experiencing newly practiced principles for improvement in a real-life setting). As such, the practice-based approach is rather focusing on the active experimentation stage and the concrete experience stage of Kolb's learning cycle. Figure 11 (see subtitle 'Employee education and training: a theory based approach) gives an overview of which pedagogical and didactical formats are available to stimulate reflective observation and/or abstract conceptualization in the theory-based approach towards education and training. Next, a practice based approach visualizes which pedagogical and didactical formats are available to stimulate active experimentation and concrete experience in the practice-based approach towards education and training.

Employee education and training: a theory-based approach

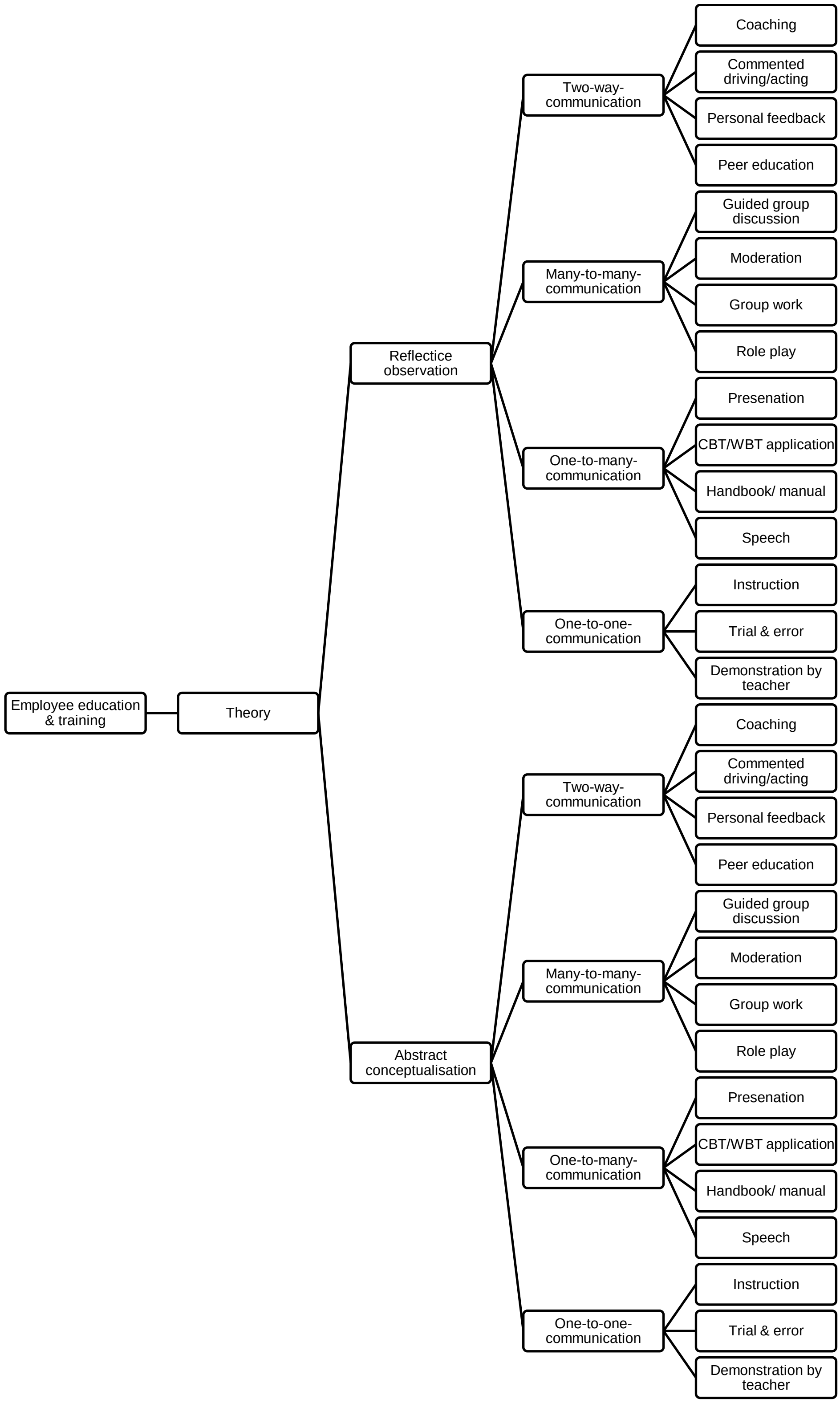

Figure 11: A theory-based approach towards (professional) driver education and training: overview of pedagogical and didactical formats to stimulate reflective observation and abstract conceptualization

As can be derived from Figure 11 reflective observation and abstract conceptualization can be realized by means of several more specific pedagogical and didactical formats. The overview presented in Figure 11 was inspired by and drawn from the RUE-project (www.cieca.eu and Schulte et al., 2014; Weiße et al., 2015), as it was one of this project's key-objectives to inventory available pedagogical and didactical formats and to examine their suitability for educating and/or training the various driver-related competences of the famous Goals for Driver Education (GDE) Matrix. As shown, both reflective observation and abstract conceptualization can be implemented in four different settings in terms of how communication is organized, i.e. two-way communication, many-to-many communication, one-to-many communication, and one-to-one communication. For each of these settings, more specific pedagogical and didactical formats can be identified according to the RUE-project.

For instance, in a two-way communication setting, four specific formats can be adopted, i.e. coaching, commented driving/acting, personal feedback, and peer education.

- Coaching: Even though Karlsson et al. (2017) indicate there is no commonly shared formal definition of what is meant by the term 'coaching', Schulte et al. (2014: p. 46) describe coaching as "[…] designed to improve existing skills, competence and performance, and to enhance [coachees'] personal effectiveness or personal development or personal growth." The authors further add to this description that coaching is a learner-centered method engaging body, mind and emotions to develop inner and outer awareness and responsibility with an equal relationship between the learner and the coach. Furthermore, Schulte et al. (2014) specify that the essence of coaching is the idea of partnership, i.e. the coach not being a 'knowledge pool' but an 'interested companion' allowing the coachee to find his/her own way by the help of sophisticated questioning. According to Karlsson et al. (2017), it is important to further specify in function of who acts as coach since it can be a critical use parameter that has impact on the effectiveness of coaching. More in detail, a coaching role can be adopted by an externally hired person, a superior in the organization, a peer within the organization, or technology (i.e. virtual coaching or e-coaching). Even though there is no so much systematic scientific evidence in the field of professional driver training and education to backup this claim, several projects in the domain of basic driver education for young novices have focused on the key-principles of coaching and how to correctly implement these, in the assumption that a coaching style is more effective than an instructive teaching style e.g. the MERIT-project (Bartl et al., 2005), and the HERMES-project (www.alles-fueherschein.at/HERMES).

- Commented Driving/Acting: Although mainly implemented in the context of practice-based education and training, commented driving is a pedagogical format that can also be applied in theory-based settings (for example, a one-to-one session with a coach) where (video) recordings are used retrospectively as stimuli materials to trigger reflective observation and abstract conceptualization. Schulte et al. (2014: p. 47) define commented driving as a technique where the student (pupil) is telling everything that he/she observes, thinks, transfers and is doing in different traffic situations." In addition, there is no research available where this approach has been studied in the context of professional driver training, so there is no real indication of the effectiveness of this technique. When applied in a practice-context, this technique can be useful (for instance to train hazard perception and hazard responsiveness), as was demonstrated in studies with young novice drivers (e.g. Isler et al., 2009; Crundall et al., 2010).

- Personal feedback: Schulte et al. (2014: p. 49) consider this technique to be valuable more specifically when the aim is to build up the competence of self-evaluation. Basically, personal opinions, attitudes or (observed) behaviours serve as the starting point of a conversation where a coach supports the coachee's thinking by means of open questions, and listens to ask more in-depth questions if necessary. The MeBeSafe project is currently exploring the added value of this avenue (i.e. one-on-one assessment of recorded safety-related events further enriched with contextual information based on dashcam recordings) in the context of coaching professional truck operators (see Deliverable 4.2. by Bakker et al., 2018). Overall however, it can be assumed that this is a very promising technique since multiple studies have documented that (professional) drivers highly appreciate personalized feedback (see for instance Roetting et al., 2003; Huang et al., 2005; Zhang et al., 2006; Huang et al., 2008).

- Peer education: is described by Schulte et al. (2014: p. 49) as a technique where a peer mentor presents his/her own experiences in road traffic to the learner, with inclusion of personal motives, situational circumstances, experience consequences, and lessons learned. The learner then has the opportunity to ask for details and discuss. This approach has mainly been studied in the literature on so-called victim testimonials (see for instance the CLOSE TO-project: www.close-to.net, or Cuenen et al., 2014), albeit that strictly taken, most of those studies were done in a many-to-many setting, rather than in a two-way setting. Besides these victim testimonials, other applications of peer education have occasionally been described, but without systematic research on the effectiveness of this technique. Irrespective of that, various studies have found that professional truck drivers do seem to particularly appreciate and value feedback and recommendations from professional peers (see for instance Zhang et al., 2006; Huang et al., 2008).

Many-to-many communication is a totally different setting. The RUE-project proposes the following four pedagogical and didactical formats: guided group discussion, moderation, group work, and role play.

- Guided group discussion: Schulte et al. (2014: p. 47) explain this as a method where a discussion leader tries to have group members openly discuss certain topics based on a series of questions, but with an eye for structured progress in a sense that the discussion should follow the content. Moreover, the different inputs and perspectives received should be summarized and in some way or another result in a conclusion. The authors consider this to be a useful method for classroom training and applications of this technique have been studied, for instance, in the context of post-licence training for young novice drivers (e.g. Brijs et al., 2014). Most of these post-licence training programs indeed include a group discussion component (e.g. the NovEV-project by CIECA: see Sanders and Keskinen, 2004), and even though there are indications that these contribute to the effectiveness of such programs (e.g. BASIC-project by CIECA: see Hatakka et al., 2003), results across different studies are not consistent (e.g. Ker et al., 2005). Moreover, in the majority of the cases, the net impact of such a guided group discussion component on program effectiveness was not determined because it was not possible to isolate the contribution of that specific component from other intervention techniques applied in such post-licence programs. Turning to the literature on safety management of professional fleets, the picture that emerges from available research is that guided group discussion or ‘in-company safety meetings’ as they are often referred to are definitely applied on a wide scale and perceived as useful in the sector. As indicated by Knipling et al. (2011: p. 49), these safety meetings often include managers, dispatchers, drivers and other safety-related fleet personnel. In the so-called SafetyReturns study of top performing fleets conducted by the American Trucking Associations Foundation (ATAF, 1999), it was reported that fleets held regularly scheduled safety meetings, generally with mandatory attendance and/or paid attendance for drivers. Moreover, the study showed that topics addressed mostly were recent crashes or incidents, vehicle maintenance and inspection, defensive driving, health and wellness, fatigue management and hours of service, winter driving, loading dock practices, and hazardous material handling. The I-95 Corridor Coalition “Best Practices” study by Stock (2001) found that 76% of the responding smaller carriers (i.e. 10-24 vehicles) regularly held safety meetings, usually quarterly but sometimes even monthly. Percentages were even higher for larger fleets. In total, 87% of all respondents rated safety meetings as important for carrier safety. Also in Europe, guided group discussion belongs to the repertoire of techniques employed in the context of initial qualification and periodic training of professional truck drivers. For instance, as part of the ProfDRV-project, Burchert and Petermann (2011) reviewed methods and assessment in professional driver training in seven European countries (i.e. Germany, Austria, Hungary, the Netherlands, England, Spain, and Italy). They reported that trainers or coaches in some cases indeed foster sharing of experiences between drivers as a way to initiate group discussion. In those cases, it was considered as important that drivers are to be kept alert by asking questions or requesting personal opinions, all in plain and clearly understandable language. Irrespective of the fact that safety meetings and guided group discussions are perceived as important, the empirical evidence supporting this opinion based on experimental work or actual field trials is sparser than cross-sectional survey work that has been conducted on this topic.

- Moderation: is narrowly related to group discussion, even though there is one explicit distinction to be made. According to Schulte et al. (2014: p. 49), the key-difference is that in the case of moderation, the moderator does not give the learning- or discussion goal beforehand. There is no awareness of studies that have investigated this particular technique in the context of professional driver education and training. It is therefore difficult to estimate the effectiveness of moderation as a pedagogical format.

- Group work: is described by Schulte et al. (2014: p. 48) as a technique where people work in smaller groups and receive a worksheet with questions that address certain driving-related issues that need to be discussed in-group to result in identification of pros and cons. The findings in each group are then presented to the plenary group. To the best of our knowledge, left aside some descriptive cases, there is no systematic research available that has examined the effectiveness of this particular technique in the context of professional driver education and training.

- Role play: as explained by Schulte et al. (2014: p. 50), in role play the purpose is to mimic different road users in an imagined context and actively involve the learner by having him/her pick up a role to play. This technique has been proposed as a useful in the context of basic training for young novice drivers, but it is known that it has not yet been applied in studies on professional driver education and training.

One-to-many communication is the third setting identified in the RUE-project where it has been associated with the following pedagogical and didactical formats: presentation, Computer Based Techniques (CBT) or Web Based Techniques (WBT), handbook/manual, and speech.

- Presentation: is described by Schulte et al. (2014: p. 50) as a technique that is mainly aimed at creating structure and overview. Typically, supportive materials are used such as a powerpoint presentation, screenshots, pictures, photos, videos or movie trailers. It is ideally suited for a classroom training. In the CTBSSP Synthesis 13, Brock et al. (2007) overviewed different training strategies and methods applied in the commercial vehicle sector in the US, and the conclusion was that the traditional core instructional method of classroom lectures was a predominant technique. They also reported that classroom lessons were often supplemented with written materials, and further enhanced by audiovisual presentations. In their review of training practices in seven European countries, Burchert and Petermann (2011) also mentioned that training lessons are often supported by multimedia tools like powerpoint presentations, films, photos, et cetera. In some cases (for instance in Germany) trainers adapt their materials to the firm whose employees they are qualifying, via the use of pictures of accidents that occurred with trucks owned by the company, or by means of educative videos provided by producers of the trucks used by the company. Yet, more specifically in Germany, criticism was also expressed, mainly towards the use of powerpoint presentations meant to make teaching more vivid, as over-visualization creates a potential risk of flattening the learning process.

- CBT or WBT: Knipling et al. (2011: p. 50) state that E-learning comprises various modes of remote web- and computer-enabled techniques, such as computer-based training or web-based instruction. Schulte et al. (2014: p. 47) argue that CBT or WBT can be used by learners to assimilate contents. This can be done for instance, by simply providing explanations, or by providing questions to be answered relate to the targeted content. In the TRAIN-ALL-project, Lang et al. (2007: p. 44-50) proposed a classification of multi-media tools that was based on the level of interaction between the user, the tool, and the task required by the user (e.g. simple observation of scenarios, active participation, et cetera). They distinguished three types, i.e. (1) multi-media tools that do not require interaction with the training software, (2) multi-media tools based on answering questions, and (3) multi-media tools that require prediction and progress of scenarios or determination of risks. Important noticing is that, since our focus currently is on theoretical approaches (instead of practice-based approaches) meant to stimulate reflective observation and/or abstract conceptualization, CBT/WBT here refers only to the first two types proposed by Lang et al. (2007). The third type is practice-oriented and therefore, falls under the practice-oriented approaches. Over the last decade, E-learning in its various forms definitely received much attention. Altogether, it seems there are proponents as well as opponents to the application of E-learning for professional driver education and training (e.g. the TRAINER-project: see Baten and Bekiaris, 2003). On the one hand, several advantages have been associated with E-learning. Welsh et al. (2003) conducted a systematic overview of E-learning experiences based on empirical research and a questionnaire. They identified the following benefits: (1) consistent training across multiple locations, (2) cost reduction, in particular travel costs, classroom costs and time-off-the-job costs, and (3) harmonization of training materials. Knipling et al. (2011: p. 50) refer to a 12-year meta-analysis of E-learning research by Means et al. (2009) where the following benefits of interactive E-learning were identified: (1) improved knowledge and performance for most topic areas, (2) increased access with reduced travel time and expenses, (3) convenience & flexibility to learners, (4) sharper focus on required knowledge, skills and competences, (5) more likely to be the product of a systematic instructional design process, including validation of learning objectives and instructional content accuracy, (6) eliminates variations in learning arising from variations in instructor knowledge and competences, (7) better spacing of learning, allowing consolidation of knowledge between sessions, (8) reduced overall training time, (9) economies of scale, (10) better tracking and recording of trainee, organizational, and training system performance. Brock et al. (2007: p. 7) also refer to meta-analysis based studies that seem to be suggesting that computer-based instruction indeed seems to work (e.g. Kulik and Kulik, 1991; Kulik, 1994; Fletcher, 2006). In an FMCSA report by Brock et al. (2011), the focus was the use of Web Based Instruction (WBI), and the authors contended that WBI has particularly strong *potential* in small companies since it substantially reduces the need for both instructional facilities and expert trainers at remote locations. Furthermore, the report states that WBI and other E-learning approaches can be more interesting and engaging than conventional instruction methods. For instance, WBI can offer all sorts of high quality graphics, video and sound. Also, interactive E-learning can be tailored to the learning needs of each individual since it is possible to adapt pace, mode, content and measures of success. Moreover, detailed feedback can be provided and the learner can be supported in the selection of the most appropriate follow-up units of instruction. Reference is also made to a review study by Dodds and Fletcher (2004)where it is stated that a 'law of thirds' can be identified in the evaluation of WBI and other E-learning approaches. Generally and approximately, it would reduce training costs by 33%, reduce needed instructional time by 33%, and increase learning by 33%. In the ex-post study report on the effectiveness and improvement of the EU legislative framework on training of professional drivers, Panteia and TML (2014) a public consultation of stakeholders indicated that positive elements associated with E-learning were (1) facilitation of delivery of highly theoretical content, and (2) more flexibility compared to classroom teaching. However, despite all the above mentioned benefits, the use of E-learning is certainly not unanimously supported. The report by Panteia and TML (2014) for example showed that 60% of the stakeholders consulted during the workshop agreed that E-learning could be considered to partially replace in-house training, while 35% disagreed. Also, the survey by Knipling et al. (2011) showed that only 35 out of 111 small motor carriers responding used online training programs. Indeed, several shortcomings or disadvantages have been related to E-learning as well. According to Brock et al. (2011) WBI is not really suited for training multi-step procedures, and a potential barrier to widespread use of WBI might be the sometimes limited computer proficiency among drivers and managers, although computer literacy increased substantially over the last decade. Computer self-efficacy was also a potentially problematic factors in the study by Panteia and TML (2014), especially among older drivers who might not be as experienced as younger drivers. Additionally, E-learning was deemed as more useful for cognitive learning outcomes, particularly, less complex knowledge and intellectual skills, but less for practical training purposes. Burchert and Petermann (2011) refer to work in the field of vocational training that shows that very motivated, abstractly thinking persons benefit most from E-learning, while persons with learning difficulties or educationally disadvantaged persons often have problems with open learning settings like E-learning. Altogether, the stakeholders consulted during the workshop by Panteia and TML (2014) indicated that E-learning should only be used as a complementary tool, but not as a full replacement of other educational- and training approaches. According to authors of the report, the picture that seems to emerge from stakeholder consultancy and literature review, is that E-learning can be more suitable for some specific circumstances, and less in others, which is why implementation of E-learning should be carefully considered in advance.

- Handbook/Manual: according to Schulte et al. (2014: p. 48), handbooks or manuals mainly serve to create better understanding of content and can support learners in personally processing driving-related information. One of the key-advantages of a handbook or manual as part of professional driver education and training, is that it could be a way to standardize content. This is at least what Panteia and TML (2014) found in their stakeholder consultation workshop. More in detail, 60% of the participants said they would even prefer a uniform European syllabus as way to avoid the wild grow of manuals and handbooks that can be witnessed in several countries. Despite that, the study also showed that only nine out of 27 Member States had developed a national syllabus for periodic training.

- Speech: Is defined by Schulte et al. (2014: p. 50) as a method which is not really communicative, and where no support is being made of additional materials (like a presentation). Consequently, the learner is basically learning by listening and taking notes. Mostly this technique is applied in the context of classroom teaching.

One-to-one communication is the fourth setting identified by the RUE-project. The following pedagogical- and didactical formats have been proposed: instruction, trial and error, and demonstration by teacher. As a general remark, to the best of our knowledge, there is no systematic empirical research available where the effectiveness of these three formats has been investigated in the context of theory-based professional driver education. Therefore, there is a limitation to describing the formats, without being able to report on effectiveness or on critical implementation parameters that would impact effectiveness.

- Instruction: Schulte et al. (2014: p. 49) describe instruction as a technique where the learner gets direct information on how to act, or think. It is therefore a rather unilateral (teacher-to-learner) approach, different from what was defined earlier as a coaching style. Instruction lends itself to both practice-oriented approaches and theory-based approaches. In a theory-based setting, instruction can be used to stimulate reflective observation as well as abstract conceptualization. In the case of reflective observation, instruction would imply that the teacher brings the learner to the targeted reflections by telling him/her what to observe and what to think and conclude from that observation. In the case of abstract conceptualization, instruction would mean that it is the teacher who is fully in control in a sense that the teacher simply tells the learner what new insights for improvement can be deducted from the knowledge already present. As already indicated, over the last decade, attention shifted from instruction to coaching, although depending on the context, instruction remains a valuable technique. In case for instance where a learner has little or no knowledge or prior expertise to start from, the need for instruction might be higher than when awareness and skills are already developed up until a certain level. That's when guided discovery an coaching might become more relevant and self-learning becomes possible.

- Trial and error: is a technique that according to Schulte et al. (2014: p. 51) allows a learner to experience error or failure as a way to gain new insights or skills. This technique is also applicable to both theory- and practice-based settings. In a theoretical context, trial and error would relate to the development and improvement thinking and reasoning. The learner for instance receives a problem, a factual statement or a situational context, is free to reason on it and to reach an answer or decision. In case of error or mistake, the teacher can support the learner in reevaluating the answer provided or decision taken. In a practical setting, trial and error can be a useful technique to develop and improve skills and competences. For instance, in two famous experiments, Ivancic and Hesketh (2000) investigated the effect of making errors during training (error training) on a driving simulator versus learning from examples of errors (guided error training) on driving skill and confidence. Experiment 1 indicated that compared with errorless learning, error training resulted in significantly better transfer to driving tests that were similar to situations encountered in training and more effective use of strategies for coping with a novel driving situation. Furthermore, error training also reduced self-confidence in driving skill at the end of training relative to errorless learning. Experiment 2 provided weak evidence of the superiority of guided error training over errorless learning (where the driver in the video did not make any errors) on analogous tests, and no evidence of transfer to a novel test. Moreover, guided error training did not influence self-confidence in driving skill.

- Demonstration by teacher: is defined by Schulte et al. (2014, p. 47) as a technique where the learner copies a good practice example shown by the teacher. Demonstration closely resembles instruction, although there is a difference between the two. In the case of instruction, the teacher joins the learner in the process of acquiring new knowledge or insights, but always in the leading position, giving direction and guidance to the learner. Instruction is thus a kind of joined endeavor where together, teacher and learner set out to obtain new insights. Different from that, in the case of demonstration, the engagement on the side of the learner is rather passive. Instead of bringing the learner to new insights, demonstration implies that the teacher brings new insights to the learner, who acts more as a passive recipient than as an active companion. This technique can be applied in both theory- and practice-oriented settings. As an illustration of how demonstration can be applied in a theory-setting, think for instance of a teacher using supportive materials (like a video or a poster) to show how a certain driving technique is to be applied.

Different communication settings and their respective pedagogical and didactical formats that can be applied to stimulate reflective observation and/or abstract conceptualization in a theory-based setting were identified, described and discussed, so the next step is to move on to the practice-based approaches for (professional) driver education and training. As can be derived from Figure 12 (see subtitle 'Employee education and training: a practice based approach), three basic approaches can be distinguished, i.e. practice on track, practice in a simulator environment, and practice in traffic. While track- and simulator-based practice typically serve to try out and test newly gained insights on how to improve driving (i.e. active experimentation), practice in traffic is rather aimed at applying newly acquired competences and skills in a real life setting (i.e. concrete experience).

Employee education and training: a practice-based approach

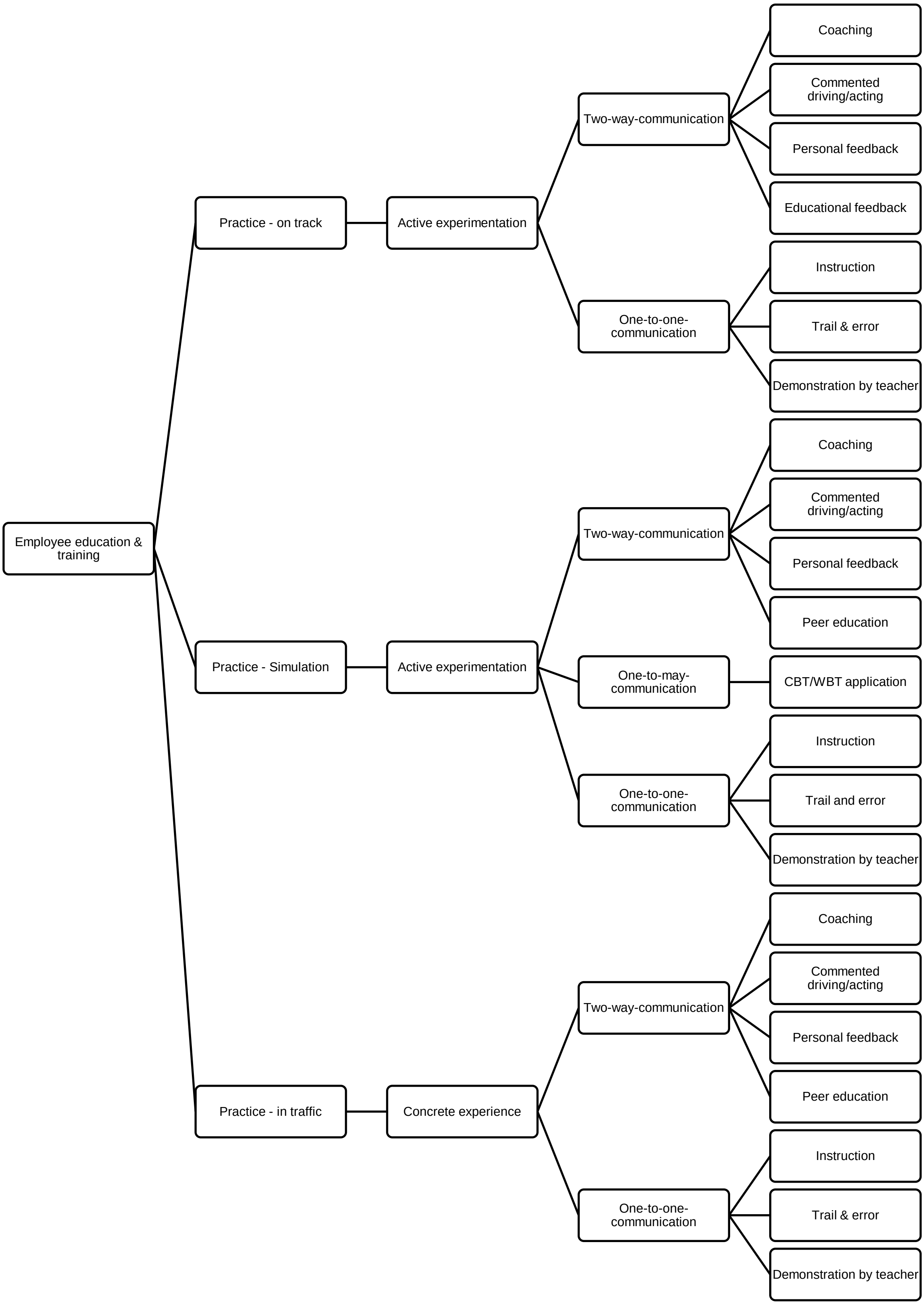

Figure 12: A practice-based approach towards (professional) driver education and training: overview of pedagogical and didactical formats to stimulate active experimentation and concrete experience

- Practice on track: As indicated in Figure 12, practice on track is related with two communication settings, i.e. two-way communication, and one-to-one communication since practice on track is rarely done in large groups. The more specific pedagogical and didactical approaches that can be associated with both communication settings were already described and discussed in the previous section (i.e. subtitle 'Empolyee education and training: A theory based approach'). Actually, very little is known about the effectiveness of track-based practice for commercial heavy vehicle drivers. As indicated in a review study by Brock et al. (2007), in the US, the favorite method for training commercial drivers is a combination of classroom lectures and supervised driving. Brock et al. (2007: p. 23) also conducted a survey among training operations, which showed that four types of skill trainings were reported by responding schools: (1) range (or track) training with students either driving a vehicle around a restricted space or riding in a vehicle driven by a different student, (2) simulator training, (3) demonstration of skills by an instructor, and (4) Behind The Wheel (BTW) on road training. Not all schools used all four methods. Interestingly, of the 36 schools that answered to the question how effective they considered the BTW on range method, 25 considered it as a most effective method. Actually, BTW on road was the only method out of a set of nine (i.e. lectures, films/videos, computer-based training, web-based, textbooks, BTW on range, simulation, demonstrations, BTW on road) that was more frequently evaluated as most effective. Yet, the survey study conducted by Brock et al. (2007) showed that more advanced training settings (such as skid pads) are employed only in the largest and most innovative schools and fleets. Overall, it is known that no systematic (experimental) research has actually explored the effectiveness of range or track-based training for professional drivers of commercial heavy vehicle drivers.

- Practice in simulator: Figure 12 shows that simulator-based practice can be associated with three communication settings, i.e. two-way communication, one-to-many communication (for instance, Cloud-based solutions that offer trainers and coaches the possibility to simultaneously download driving scenarios on different simulators and work with multiple trainees), and one-to-one communication. As stated by Brock et al. (2007: p. 8) "[s]imulation is an instructional method that requires students to interact with specific instructional events based on real-world scenarios. Students must see or experience the consequences of their interaction. All interactions should result in similar real-world outcomes or effects. The primary learning outcome of a simulation should be the demonstration of a real-world process, procedure, or specific behavioral change." In their review of simulator-based training, the authors mention that the effectiveness of simulator training for truck drivers is better documented that that for computer-based instruction and E-learning. An overview of current practices in the European Union and North America by Horn and Tardif (1999) established that truck driver training was generally rather low-tech with a preference for classic methods of teaching, and simulators probably remaining the exception mostly because of cost-related considerations. Nonetheless, there is quite some literature available that documents the use of simulators in the context of professional driver education and training. Hartman et al. (2000) for instance, reported that throughout Europe, driving simulators were becoming an important enhancement for cost-effective, safe driver training, because simulators allow year round training and are less expensive than behind-the-wheel training. The report by Pierowicz et al. (2002) assessed the adequacy of six different simulators for the training of tractor-trailer drivers. Brock et al. (2001) performed a literature review, conducted surveys and made site visits to examine the use and effectiveness of simulator training for transit bus operators. They discussed and evaluated the operational capabilities of three types of simulator technology: (1) an open-loop video simulator (i.e. the learner works on a station equipped with a steering wheel, gas and brake pedals, and a rudimentary dashboard, but engagement of any of these controls will not produce any appreciable effect on the video display), (2) a low-end simulator (i.e. a model-board system where a miniature camera is installed in a small model of a bus that physically moves about on a small terrain board in an adjoining room, and replicating the visual, auditory and vibratory effects of driving a bus in an urban, crowded environment), and (3) a mid-range simulator using realistic audio and video, including rear projection, a larger field of view (i.e. 180 degrees forward and 45 degrees vertical, and 60 degrees to the rear), together with a more sophisticated vehicle model and more complex environmental effects). They concluded that transit bus operator training can be improved with selective use of simulator systems, but also noticed that a critical feature in the success of simulator training programs was the competence and enthusiasm of the instructional staff. Regarding the latter, there is actually quite some literature that has focused on how simulator training effectiveness should be measured (Fisher et al., 2011). Perhaps, one of the best known training effectiveness measurement methodologies is the Four Level Evaluation Model as proposed by Kirkpatrick (1994). More in detail, the model shows that effectiveness evaluation can target four distinct measures, i.e. (1) reaction (how the student feels about the training received), (2) learning (to what extent knowledge, competences and skills improved), (3) performance (impact on on-th-job performance), and (4) results (what the organizational benefits from training are). Different factors have been identified that can affect the quality of simulator training. According to Mitsopoulos-Rubens et al. (2013), simulator fidelity is one of the more intensively studied factors. Essentially, in terms of fidelity, a distinction is to be made between physical fidelity and functional fidelity. Physical fidelity is about the degree to which the simulator looks and feels like a real-world operational system (Thompson et al., 2009) while functional fidelity relates to the extent to which the simulator acts like a real-world operational system (Triggs et al., 2008). Mitsopoulos-Rubens et al. (2013) refer to other factors beyond simulator fidelity as relevant determinants of simulator training quality, namely, instructional technique, training content, timing of training delivery, duration of training, training assessment, and the trainers themselves. Mitsopoulos-Rubens et al. (2013) looked at available studies on simulator training for heavy vehicle operators. On the one hand, they focused on research evidence for simulation-based training in critical technical skills (e.g. vehicle control) and non-technical skills (e.g. hazard perception) at the entry level (e.g. Morgan et al., 2011), and in the principles of eco-driving at the post-licence level on the other hand (e.g. Strayer and Drews, 2003; Parkes and Reed, 2006; Reed et al., 2007; Reed et al., 2010). They concluded that for new heavy vehicle operators, there is research evidence indicating the use of simulation in technical skills- and non-technical skills training at the entry/licencing level can be effective. Yet, that evidence mostly comes from evaluations using global (e.g. licence test scores) rather than specific (e.g. speed selection, gear choice, lane positioning) performance measures. Furthermore, the authors found that despite evidence of learning, there is only scant evidence on transfer of training to the real-world and on long-term skill retention. Regarding eco-driving training at the post-licence level for existing/current heavy vehicle operators, Mitsopoulos-Rubens et al. (2013) established that there is good evidence of learning in the simulated environment (positive effects on fuel efficiency range between 2.5% and 11%), positive transfer of training to the real-world (the study by Parkes et al., 2010 found a positive effect on fuel efficiency of 15.7%), and skill retention. Also for eco-efficiency training, most studies are based on global performance measures (e.g. fuel consumption), albeit that some have focused on specific measures as well (e.g. number of gear changes, RPM during acceleration/deceleration periods, et cetera). The study by Burchert and Petermann (2011) confirms the relevance of using driving simulators to train eco-efficiency skills in a sense that several EU-countries already implement such training (e.g. the Netherlands, Hungary, Spain, Germany). Moreover, simulators are also used to practice driving in unusual and dangerous situations, such as under bad weather or traffic conditions, or when having technical failure. According to Panteia and TML (2014) driving simulators may be particularly interesting to train higher order tasks (e.g. situational awareness or risk perception) and procedural tasks (e.g. what order of actions do I need to take in situation x, y or z?). Contrary to that, the use of simulators would not bring specific advantages in case of training tracking tasks (e.g. speed and course maintenance) and emergency situations. So, conclusively, it is reasonable to state there there is evidence available to support the usefulness of simulator training for professional heavy vehicle operators, especially in the case of training higher order skills, procedural tasks, and eco-efficiency. However, it is very hard if not impossible to evaluate which more specific pedagogical formats work well or not, based on the available literature. The point that there is large heterogeneity in terms of pedagogical formats used for simulator training without clear evidence for what can be considered as effective was also explicitly made in the TRAIN-ALL project where Bekiaris et al. (2009: p. 42) stated that: "[t]he simulator-based training curricula currently used by training providers across the EU countries seem to be predominantly created on an individual basis by practitioners and experts; therefore there is currently no standardization of simulator-based training curricula and contents. Curricula seem to rarely undergo systematic evaluation to assess training effects."

- Practice in traffic: as shown in Figure 12 practice in traffic typically takes place in one of two communication settings, i.e. two-way communication or one-to-one communication. Each of these two settings have their specific pedagogical and didactical formats. Looking at available literature, the overall picture that emerges resembles what has been already reported for practice on-the-range. Most practitioners, safety managers, company owners, professional trainers, and truck drivers subscribe to the idea that on-road behind-the-wheel training is highly effective and very useful (e.g. Brock et al., 2007; Knipling et al., 2011). Scientific experimental evidence to back-up that claim however, is not easy to find. The positive appreciation of on-road training probably comes from the belief that learning in a real-life context is the most authentic way to learn safety- and eco-efficiency related skills and competences. Also, the possibility to receive (immediate) feedback on personal performance from a guiding expert is often considered to be an advantage of behind-the-wheel training. As already reported by Burchert and Petermann (2011), there are indeed training institutions that regard working experience and practical relevance as the best training, which is why they connect initial qualification with apprenticeship in companies. The latter was for instance done in the Netherlands and Germany. The sometimes large gap between training situations on the one hand, and working life circumstances on the other hand, are indeed mentioned by company owners and fleet safety managers as an issue to be addressed. Drivers themselves also prefer pedagogical strategies that are actual and vivid, and personally relevant. Finally, it should be noted that there is no systematic research available that has empirically investigated the effectiveness of different pedagogical formats that can be applied to on-road behind-the-wheel training.

Conclusions

A whole bulk of literature is available that addresses education and training of professional truck drivers. The different pedagogical and didactical approaches that can be encountered in this particular intervention domain tried to be systematized. Most fundamentally, a distinction can be made between theory-based approaches and practice-based approaches. Based on Kolb's Learning Styles Model, a further distinction was made between theoretical approaches targeting reflective observation or abstract conceptualization, and practical approaches targeting active experimentation (i.e. practice in simulator, and on-the-range practice), and concrete experience (behind-the-wheel practice in traffic). Each of learning stages can take place in different communication settings. According to the RUE-project, possible settings are two-way communication, many-to-many communication, one-to-many communication, and one-to-one communication. These different settings in turn, lend themselves to specific pedagogical and didactical formats. And attempt was made in order to describe and discusse all of these based on what is going to be found in the RUE-project and in literature addressing these different pedagogical and didactical formats.

The overall impression is that most preferably, education and training of professional truck drivers combines theory and practice. Notwithstanding, the more traditional methods (e.g. classroom teaching, safety meetings, in-company coaching) seem to prevail, albeit that innovative approaches (e.g. remote learning, E-learning, web-based instruction, computer-based training, multi-media support, simulator techniques) more and more have found their way into the market of professional driver training and education. Legal frameworks (like Directive 2003/59/EC and Directive 2018/645) often leave room for such innovative approaches to become part of initial qualification and periodic training, but at the same time, they allow different countries to be flexible in the more precise way education and training is organized in terms of content, materials, and pedagogical and didactical formats. The resulting heterogeneity however, is not the only problem in light of the challenge to find out which education and training formats are available and proven as effective. Another issue, is that in the majority of the cases, training formats are based on well-intended but not always scientifically proven intuitions and practical experiences.

But also academic research on the topic, has its limitations. In their review study on training approaches in the bus transit sector, Brock et al. (2007: p. 21) put it quite eloquently as follows: "Do current training practices work? Certainly, this is one of the fundamental questions the research team set out to answer. Persons familiar with the motor carrier, motorcoach, transit, and school bus communities will not be surprised to learn that the answer is "yes" when opinions are sought, but only "maybe" when hard data are needed." The latter applies not only to safety-oriented training and education, but eco-efficiency targeted initiatives as well. For instance, according to af Wåhlberg and Göthe (2007: p. 2), studies examining the effect of eco-driving training overall report effects in the range of 10 to 15% reduction, even though these are effects *during* training. It is uncertain to what extent such effects transfer to normal driving over longer time periods because very little longitudinal research has been undertaken (see also at Wåhlberg, 2002, 2006). In a study on the long-term effects of training in economical driving for bus drivers in a city environment, af Wåhlberg (2007) found that, actually, the results indicated the effects were only very small. In a study on eco-driving acceptance, Thijssen et al. (2014: p. 250) confirmed this. The authors mention that reported fuel saving numbers of 5 to 26% apply to studies where effects were measured directly after eco-driving training while the long term effects are less significant with savings decreasing to 5-10% within three years, or to 2-3% after three years.

Left aside some meta-analytical work and synthesis reviews on the use of E-learning and simulator techniques, other approaches to educate and train professional drivers have not been subjected to systematic and/or experimental study. This explains why the effectiveness of professional driver education and training remains a debated and controversial topic, which prevents us to come to firm and evidence-based conclusions as to which pedagogical and didactical approaches can be considered as effective, or why.

2.7 The use of gamification within safety interventions

Gamification is about the application of game-specific design elements, mechanisms and features outside the context of entertainment and play, i.e. in a non-gaming context (Deterding, et al., 2011; Rigby and Ryan, 2011; Burke, 2014). The main purpose of Gamification is to trigger the motivation to reinforce, change or shape a desired behaviour, and to sustain this effect over time by developing so-called intrinsic motivation. The concept of intrinsic motivation comes from Self-Determination Theory (see Deci and Ryan, 1985), and stands for the idea that humans under the right conditions, perform tasks for the pleasure of the task itself rather than for any kind of reward. Behaviour triggered by intrinsic motivation has indeed been shown to last longer than when externally motivated. According to Self-Determination Theory, intrinsic motivation requires the satisfaction of three basic human needs, i.e. (1) a feeling of competence (the idea that one is able to perform a certain task or behaviour), (2) a feeling of autonomy (the idea that the decision to engage in certain a task or behaviour is under personal control), and (3) a feeling of relatedness (the idea that engagement in a certain task or behaviour connects to and is meaningful for important social referents). Gamification is actually about the use of game design elements to satisfy these three basic human needs. Over the past two decades, numerous gamification features have been described and applied in a wide variety of behavioural domains. According to a review by Hamari et al. (2014), the effects of Gamification are generally positive, although moderated by several factors such as the context in which it is applied, and the profile of targeted users. van Gent et al. (2019: p. 206) give several examples of studies where principles of Gamification have already been applied to the field of transportation, such as for the promotion of eco-efficiency (see EcoChallenge by Ecker et al., 2011, or the gamECAR-project: www.gamecar.eu), or the improvement of driving styles (see I-GEAR by McCall and Koenig, 2012; or 'Driving Miss Daisy by Shi et al., 2012).

In 2009, Oinas-Kukkonen and Harjumaa proposed the Persuasive Systems Design (PSD) Model in a conceptual and theory-creating article (Oinas-Kukkonen and Harjumaa, 2009). As argued by van Gent et al. (2019), the PSD Model actually integrated the principles behind the Fogg Behavioural Model, Behavioural Economics, and Gamification. It is important that according to the PSD Model, (1) a system can become persuasive, if it supports the user in four possible ways, i.e. either by providing primary task support, dialogue support, social support, or system credibility support, and (2) a system can achieve these functionalities if it adopts the principles for behavioural change that have been documented in the FBM, in Behavioural Economics, and in Gamification. The four support strategies in the PSD Model each represent a persuasive feedback approach in our taxonomy of interventions falling under domain 2: Performance Monitoring and recognition. Notice of course that these four persuasive feedback approaches can be combined with each other.

Two additional remarks are to be mentioned at this point. First of all, while van Gent et al. (2019) in their article exclusively focus on *real-time* primary task support, the focus in this report is on pre- or post-trip primary task support. In other words, focus is given on persuasive feedback strategies that aim to improve a safe and eco-efficient driving style without interfering truck operators while driving, for example, via app-, website, or e-mail-based communication before beginning or after completing a trip. Secondly, van Gent et al. (2019: p. 203) focus on safely persuading driver behaviour *at the tactical level*, i.e. the level where drivers decide upon and perform manoeuvres (e.g. change lane, take exit or overtake a car). Yet, as the authors argue, driving behaviour can actually be divided into three levels, i.e. the control, tactical and strategic level (e.g. Michon, 1985). Situated at the control level, are vehicle operating skills like using gears, operating brake- and acceleration pedals, setting rearview mirrors, using blinkers, et cetera. The strategic level is more related to route choice-related decisions, which are typically covering longer time episodes (e.g. when to start a trip, which route to follow, what travel modality to use, et cetera), and to strategies to cope with factors that relate to the trip context itself (for instance, how to deal with possible sources of distraction).

Different from van Gent et al. (2019), focus in this report is given not only on the potential of persuasive feedback in a pre- or post-trip setting to influence driver tasks situated at the tactical level, but on tasks situated at the control level and the strategic level as well. The fact that pre- or post-trip persuasive feedback has the potential to influence behaviours situated at the control-, tactical, as well as the strategic level, can be derived from projects like for instance eCoMove, where persuasive feedback in a pre- or post-trip setting has not only been used to influence the tactical level of the driving task, but behavioural parameters like gear shifting or braking (i.e. tasks situated at the control level), and strategic decisions (e.g. selection of the most eco-friendly route) as well.

Turning back now to the four persuasive feedback approaches identified based on the PSD Model by Oinas-Kukkonen and Harjumaa (2009), the first approach is one where an in-vehicle monitoring system provides primary task support in a pre- or post-trip setting (for instance via an app, website, or e-mail). In the i-DREAMS project, primary task support is actually aimed at successful and efficient completion of the driver task with a specific focus on how safely and eco-efficiently drivers operate their vehicle. The second persuasive feedback approach (i.e. dialogue support) is aimed at establishing a longer term connection with the driver as a way to keep him/her motivated to work on a more continuous improvement of his/her own driving style in terms of how safe and eco-efficient it is. The relevance of this particular approach can be derived from research both within as outside the field of transportation, where it has been shown that one of the difficulties of technology-mediated behavioural change strategies, is to keep drivers actively engaged and sustain their loyalty over longer time episodes (see for instance Musicant et al., 2015). It has indeed been observed before that even though technology-mediated interventions with a persuasive purpose have many advantages (e.g., delivery of sophisticated versions of individualized feedback, the provision of context-sensitive feedback, the possibility to reach large numbers of people while maintaining relatively low costs), it remains a challenge to avoid dropout or premature attrition from follow-up sessions (e.g. Brouwer et al., 2008; Crutzen et al., 2008; Brouwer et al., 2010; Brouwer et al., 2011; Bouton, 2014). The third persuasive feedback approach (i.e. social support) hinges upon the idea that humans continuously crave for social connectedness, and individual behaviour in the context of social life phenomena (like participating in traffic) is significantly regulated by social norms (Pratkanis, 2014). The latter have been defined by Rakotonirainy et al. (2014: p. 150) as "[…] conventions emerging from a group of people that directs or specifies how people must, should or could behave in various situations." As such, social norms can be considered as a set of rules or standards that are understood by members of a group, guiding their behaviour in the context of social interactions. This is why according to Rakotonirainy et al. (2014), social norms can be a powerful leverage for persuasion, also in the context of transportation. The fourth persuasive feedback approach (i.e. system credibility support) is based on the finding that trust and acceptance are key-determinants of whether (or not) drivers will follow up on technology-provided feedback (e.g. Risto and Martens, 2013; Regan et al., 2014). Indeed the factor 'trust' appears in some way or another in theoretical models on technology acceptance such as the Unified Theory of Acceptance and Use of Technology (UTAUT; Rahman et al., 2018).

As discussed, the PSD Model by Oinas-Kukkonen and Harjumaa (2009) proposes several design principles that can be adopted in order to enable technology to provide the four persuasive approaches just mentioned (i.e. primary task support, dialogue support, social support, system credibility support). In fact, these design principles represent behavioural change techniques drawn from the various theoretical paradigms which were discussed earlier, i.e. the FBM, Behavioural Economics, and Gamification. Over the last five years, several more systematic studies have been published on the use and usefulness of gamification across different areas within health psychology (e.g. Alahaivala and Oinas-Kukkonen, 2016; Edwards et al., 2016), but in the field of transportation as well. For instance, Magana and Organero (2011), Organero and Magana (2014), Magana and Organero (2015) and the gamECAR-project applied gamification to eco-driving. Lieberoth et al. (2018) investigated gamification as an approach to promote public transport. Weber et al. (2018) studied the relevance of gamification to increase cycling. Ambrey and Yen (2018) examined the use of gamification for the encouragement of safe driving behaviours among young drivers. Riaz et al. (2019) implemented gamification in an e-learning platform to promote traffic safety among elementary school pupils. Once the variety of gamification features described and implemented started to grow considerably, specialists in the field tried to group these features into clusters. These clusters were formed in function of the idea that when gamers play, they are driven by needs they hope to satisfy through game play (e.g. Tuuanen and Hamari, 2012). Some people for instance play to win, others to explore, to collect, or to socialize with others. Depending on which is/are the primary need(s) that drive gamers to play, some game-specific features will be more effective than others to reach satisfaction (Rigby and Ryan, 2011). For instance, appearing top ranked in a leaderboard might satisfy a player who is driven by the need to achieve, while a player who is mainly driven by curiosity might not be that interested in a leaderboard. Two taxonomies grouping gamification features into different clusters in function of the targeted player needs have received particular attention in the literature on gamification, i.e. Richard Bartle's Player Types Taxonomy (Bartle, 1985, 1990a, b) and the Octalysis Framework from Yu-kai Chu (2014).

Bartle's Taxonomy originally described players of Multiplayer Online Games (MUDs), and distinguishes between four player characters, i.e. achievers, explorers, socializers, and killers. An achiever is a person who prefers action and is world-oriented. Achievers give themselves game-related goals and vigorously set out to realize them. For achievers, the point of playing is to master the game. Achievers are proud of their formal status in a game's build-in hierarchy, and of how short a time it took them to reach it. Explorers are more interested in interacting with the world and like it to be surprised by the game they play. Explorers are proud of their knowledge of a game's finer points. Socializers are primarily interested in interacting with other players, finding out about people, and getting to know them. The game world is no more than a setting, it is the characters that make it compelling. Socializers are proud of their friendships, their contacts, and their influence. Killers are mostly interested in doing things to people, i.e. acting on other players. Usually, they do so without consent of others. Killers want to demonstrate their superiority over fellow humans and are proud of their reputation and the skills they master.

The Octalysis Framework proposed by Yu-kai Chu distinguishes between eight so-called 'drives' that motivate gamers to play, i.e. (1) epic meaning and calling, (2) development and accomplishment, (3) empowerment of creativity and feedback, (4) ownership and possession, (5) social influence and relatedness, (6) scarcity and impatience, (7) loss and avoidance. Additionally, the Framework associates each of these eight player drives with specific game features that are most suited to satisfy these drives. The first core drive, i.e. epic meaning and calling implies a person thinks he or she is doing something greater than oneself, or was chosen to take action. Without receiving any extrinsic reward, the feeling that one contributes to a shared higher goal is sufficient to stay engaged. Typical game features related to this drive are pictured in Figure 13 below. Development and accomplishment is the internal drive of making progress, developing skills, and overcoming challenges (for typical game features related to this drive Figure 13). It closely resembles the achiever profile in Bartle's Player Types Taxonomy. Empowerment of creativity and feedback is a drive that gets expressed when people are engaged in a creative process where they repeatedly figure out new things and try out different combinations. Importantly, people stimulated by this drive not only need ways to express their creativity, but also want to see the results, receive feedback, and adjust if necessary (for typical game features related to this drive Figure 13.

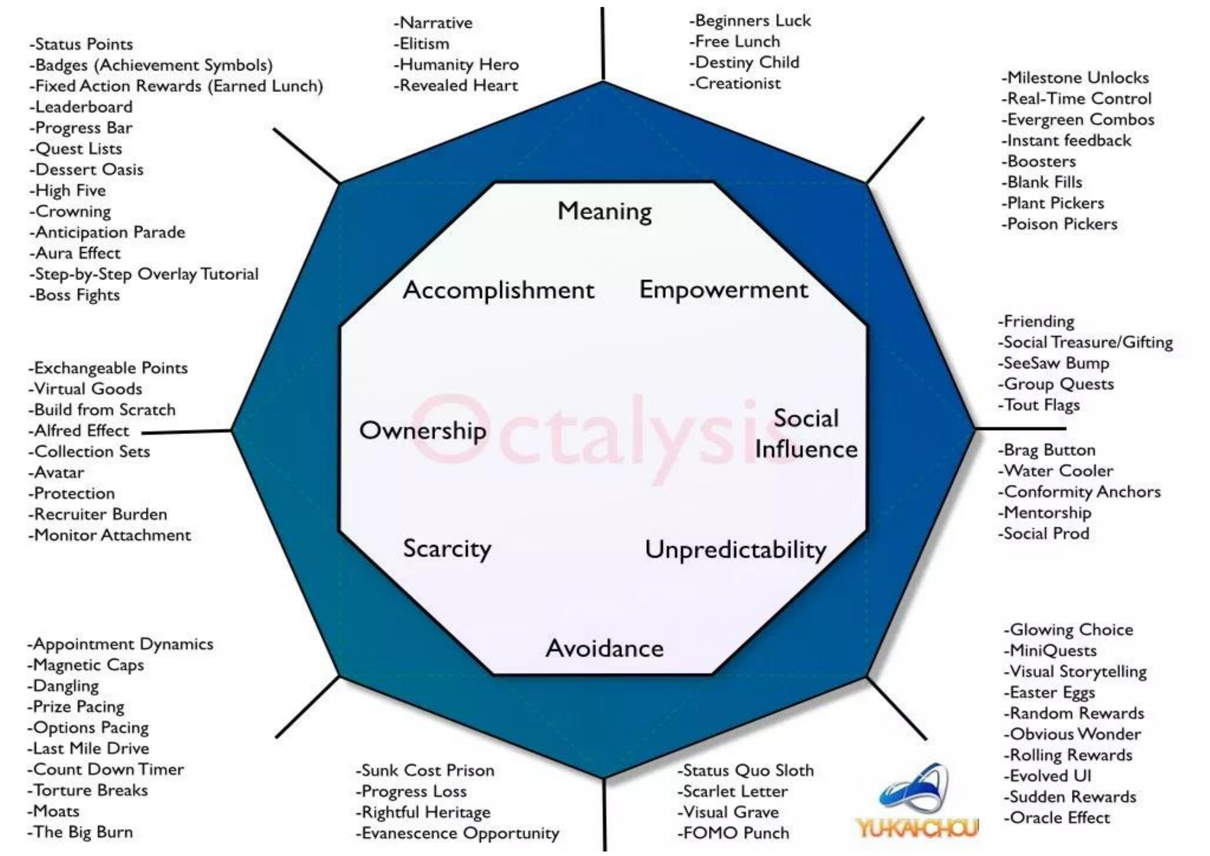

Figure 13: the Octalysis Framework by Yu-kai Chu. Source: www.yukaichu.com

The drive of ownership and possession is when people are motivated because they want to own or control something. The feeling of ownership creates commitment to further improve what is already being owned. It relates for instance, to the human desire to accumulate wealth, and overvalue objects within one's possession. See Figure 13 for typical game features related to this drive. Social influence and relatedness is narrowly related to the socializer profile in Bartle's Player Types Taxonomy. This drive actually includes al social elements that stimulate people, going from mentorship, acceptance, social responses, and companionship to envy and competition as well. Behind all these drives, is the basic idea to naturally feel attracted by and want to draw closer to people, places, events or behaviours which can be related to. Moreover, seeing an important social referent being very good at something might become a drive to personally attain the same level of skill or expertise (for game features that typically relate to this drive, see Figure 13). Scarcity and impatience is the drive of wanting something because you can't have it, or because it is really exclusive, rare or immediately unattainable (for related game features, see Figure 13). Unpredictability and curiosity is the drive of being engaged because you don't know what is going to happen next. The unexpected can indeed be attractive (see Figure 13 for related game features). This core drive is closely related to the explorer profile in Bartle's Player Types Taxonomy. Finally, loss and avoidance is the drive that motivates people to prevent negative things from happening, or to avoid the feeling that an interesting or rewarding opportunity would be missed or get lost. The work of Andrzej Marczewski builds further upon taxonomies like those proposed by Richard Bartl and Yu-kai Chu. It can actually be seen as a kind of meta-synthesis of player typologies. Marczewski has disseminated his work on gamification via the website www.gamified.uk and has already published several books on the topic (e.g. Marczewski, 2017a, b; Marczweski, 2018). Without the intention of being exhaustive, in his Gamification Design Framework, Marczewski proposed a summary overview of the most popular player types, the basic gamification dynamics and for each of these, the most frequently used gamification mechanisms. This resulted in two complementary frameworks, namely, the so-called User Types Hexad, and the Periodic Table of Gamification Elements (for more detailed information, see www.gamified.uk). Figure 14 shows the User Types Hexad.

Figure 14: the User Types Hexad by Andrzej Marczewski. Source: www.gamified.uk

As can be seen, Marczewski distinguishes between six player types (i.e. achievers, socializers, philanthropists, free spiritists, players, and disruptors), and six dynamics that drive game players, and keep them engaged, depending on what player type is being considered (i.e. mastery, autonomy, purpose, relatedness, reward, and change). Achievers are motivated primarily by mastery: they are looking to learn new things, to overcome challenges, and to improve themselves. Socializers are driven by relatedness: they want to interact with others and create social connections. Philantropists are motivated by purpose and meaning: they are altruistic, want to give to other people and enrich others without expectation of reward. Free spiritists are motivated by autonomy and self-expression: they want to create and explore. Players are driven by rewards: they will do what is required to collect rewards/ they are primarily self-oriented. Disruptors are motivated by change: overall, they want to disrupt the system, either directly through other users to force positive or negative change. Complementary to the information in the User Types Hexad, is the Periodic Table of Gamification Elements.

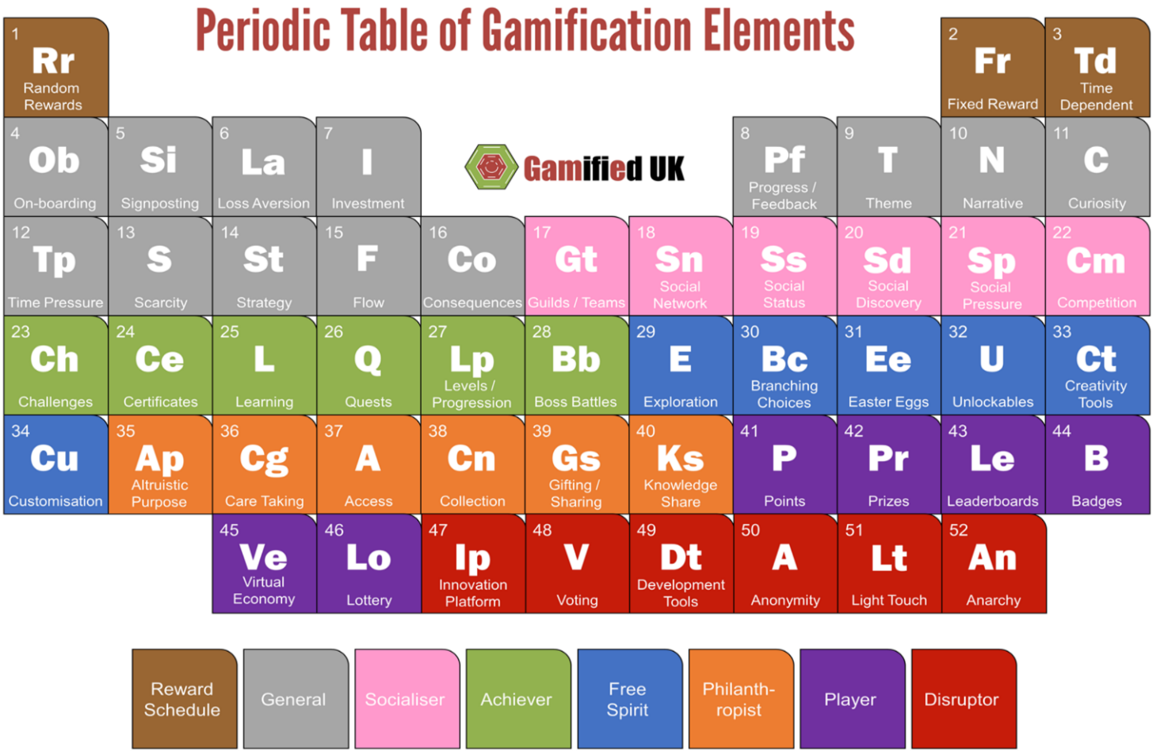

Figure 15: the Periodic Table of Gamification Elements by Andrzej Marczewski. Source: www.gamified.uk

The Periodic Table actually shows which gamification mechanics can be used to satisfy the dynamics that drive the six player types proposed in the User Types Hexad, as shown in Figure 15. More in detail, besides a set of so-called 'general' mechanics and the principle of reward schedules which both can be considered as typical ingredients of a standard game, the Periodic Table relates six gamification mechanics to achievers (i.e. challenges, certificates, learning, quests, levels/progression, and boss battles). Six other mechanics are specifically tailored at socializers, i.e. guilds/teams, social networks, social status, social discovery, social pressure, and competition. Philantropists are mainly attracted by the following six mechanics: altruistic purposes, care taking, access, collection, gifting/sharing, and knowledge share. Six other mechanics are primarily targeted at free spiritists: exploration, branching choices, Easter eggs, unlockables, creativity tools, and customization. Players are more sensitive to the six following mechanics: points, prizes, leaderboards, badges, virtual economy, and lottery. Disruptors are attracted more by the remaining set of mechanics, i.e. innovation platforms, voting, development tools, anonymity, light touch, and anarchy.

Returning to Figure 8 where the different intervention approaches in the domain of Performance Monitoring and Recognition (i.e. in-vehicle monitoring with information, in-vehicle monitoring with feedback, and in-vehicle monitoring with persuasive feedback), were shown, the different user types from Marczewski's User Types Hexagon - the related gamification mechanisms have been adopted as outlined in the Periodic Table can be implicitly associated with the different user types, and the different user types and their respective gamification mechanics were related to three out of the four persuasive feedback functionalities (i.e. primary task support, dialogue support, and social support) as they were proposed in the PSD Model by Oinas-Kukkonen and Harjumaa (2009).

As can be seen, achiever-, free spiritist-, and general mechanics were linked to the primary task support functionality. This is based on the idea that the most important objectives of the primary task functionality are to allow people to (learn how to) execute a certain task as accurately as possible (which aligns nicely with the drive that motivates achievers), to offer a tailored and personalized experience to increase learner efficiency, and stimulate self-monitoring (which matches the drive that motivates free spiritists), and to offer structured support and the opportunity to learn in a stepwise and progressive way (which is in line with general gamification mechanics like on-boarding, signposting, progress, flow, and time pressure).

The dialogue support functionality was asociated with reward-, player-, disruptor-, and another set of general gamification mechanics. Again, the research based on the PSD Model by Oinas-Kukkonen and Harjumaa (2009), from which can be derived that dialogue support is primarily aimed at praising and rewarding people (which is in line with the reward drive and the main motivation of a typical player), stimulating similarity and liking (which is relevant for disruptors in a sense that if they do not like the system support provided, they should have the possibility to make the desired changes), and keeping a close contact with people (which aligns with some general gamification mechanics that try to create a personal connection such as a theme, a narrative, investment, or curiosity).

Different from that, the social support functionality is clearly related more to what drives socializers and philantropists. Indeed, the social support functionality wants to stimulate social learning, normative influence, social facilitation, and cooperation (which matches the drives of a philanthropist). Yet, at the same time, the social support functionality tries to promote social comparison, competition, and recognition (which is more in line with the primary motives of those socializers who are sensitive to social reputation and the opinions of others). Finally, the fourth persuasive functionality (i.e. system credibility support) is less related to principles of gamification, and more to principles like trustworthiness, expertise, authority, third-party endorsement, verifiability, and real-world feel (see Oinas-Kukkonen and Harjumaa, 2009: p. 494).

Several of the above mentioned gamification mechanisms have already been applied and explored in the literature on safety and eco-efficiency. The *score* mechanism was probably one of the first explored gamification mechanisms. Toledo and Lotan (2006) for example found that exposing drivers to safety-related scores, calculated based on in-vehicle monitoring and provided to drivers via personal web pages, had significant positive impact on driver performance.

Another intensively studied gamification mechanism is the use of *rewards* (whether financial, symbolic or material). It has received attention in the literature on young novice drivers, especially in studies investigating the impact of Pay-As-You-Drive systems (e.g., Lewis-Evans et al., 2013; Dijksterhuis et al., 2015; Musicant and Lotan, 2016; Stevenson et al., 2017; Mortimer et al., 2018). Elvik (2014) conducted a systematic review of seven trials designed to reward safe and environmentally sustainable driving and concluded that they were all successful in promoting the rewarded behaviours, with the largest effects found for rewarding compliance with speed limits. However, since drivers volunteered to participate in these trials, a self-selection bias cannot be excluded and findings not just be generalized to drivers in general. Reward strategies have also been applied in the context of professional fleet safety management, mostly as part of a broader Compliance, Safety and Accountability (CSA) program (e.g. Stock, 2001). Knipling et al. (2011) for instance mention that one popular form of rewarding in the sector of commercial motor vehicles, is to positively recognize safe behaviours in order to reinforce safety improvements. Material rewards such as pay bonuses may be used, although many fleet safety practitioners believe that awarding large pay bonuses for safety can become a source of discord within organizations, as those not receiving awards may believe they are being treated unfairly. Based on the FMCSA/UM Survey of Safest Motor Carriers, Corsi and Barnard (2003) observed that types of rewards in use included verbal praise, public recognition, and letters from management, safety decorations, cash, and merchandise. Ordinarily, rewards were time-based rather than mileage-based.

The reward mechanisms has also been applied to the promotion of energy-efficient behaviours at work, among which eco-driving. Schall and Mohnen (2017) for example investigated the usefulness of both monetary- and non-monetary rewards on the promotion of eco-driving based on a six months long controlled natural field experiment with drivers of light commercial vehicles in different branches of a logistics company. Results showed a reduction of fuel consumption of 5% due to a tangible non-monetary reward and suggested only a small reduction of the average fuel consumption in the equivalent monetary reward treatment. Rewarding strategies might thus be a valuable approach to stimulate positive (i.e. safe and/or eco-efficient).

However, as far as professional fleet safety management in the commercial vehicle sector is concerned, Knipling et al. (2011: p. 53) mention that besides structuring a system for recognition and rewards for safe driving behaviours, nearly all carriers must also issue reprimands and penalties for driver offenses. This brings us to another set of gamification mechanisms, i.e. consequences and loss aversion. Various surveys have indeed shown that managers consider punishments as an effective strategy to eliminate specific unwanted behaviours (e.g. Corsi and Barnard, 2003; Knipling et al., 2003). Research has shown that it is important that penalties are applied uniformly for specific, announced behaviours (e.g. exceeding speed limits) or non-behaviours (e.g. not wearing the seat belt). Moreover, punishments need to be timely and certain, but they do not necessarily have to be severe in order to be effective. Penalties should be in response to specific behaviours, not personality traits or attitudes. Put differently, they should comply with the principle ‘punish the sin but not the sinner’ (e.g. Hickman et al., 2007; Knipling, 2009).

The mechanism of social pressure has also been studied already, for instance in the literature on parenting of young novice drivers (e.g., McGehee et al., 2007; Farah et al., 2013). In general, it was found that the combination of in-vehicle monitoring and parental feedback and guidance can be a successful strategy to reduce risk-taking behaviours, even though it depends on several implementation-related aspects, such as tone of voice, coaching style adopted, et cetera.

In a simulator study on the promotion of eco-safe driving, Vaezipour et al. (2019) explored the usefulness of feedback in combination with incentives and competition. They found that adding an incentive and competition to feedback resulted in a 4.7% reduction in fuel consumption. The principles of personalization, (historical) progress, and learning were investigated by Brouwer et al. (2015) in an explorative driving simulator study to improve eco-driving. They found that using a display that gives historical feedback and that incorporates learning elements suggested a non-verifiable increase in terms of acceptance. However, the authors argued that maybe, historical feedback and learning elements are less effective for performance oriented drivers who may need comparative feedback and game elements to improve energy conserving driving behaviour. The principle of adaptive learning was part of a study by Pozueco et al. (2018) in which they developed a complete methodology to evaluate driving efficiency of professional fleet drivers. The methodology includes an early-classification component that allows to establish the initial efficiency level of the individual driver, which permits an adaptation of the learning process from the beginning.

Tips and recommendations are another principle that has been studied. Staubach et al. (2014) conducted a driving simulator study to investigate the impact of an eco-driving support system. The system was able to communicate with traffic lights and to detect traffic signs. Based on that information, the system gave recommendations to participants concerning fuel efficient gear shifting and acceleration/deceleration behaviour. The result were fuel savings between 15.9 and 18.4% because participants shifted up gears earlier and used more coasting strategies. Sureth et al. (2019) examined the effectiveness of providing eco-driving tips to drivers of hybrid electric vehicles. The authors found that tips were evaluated as largely positive, and that participants receiving eco-driving tips that focused on implementation intentions and technical explanations, significantly reduced their fuel consumption by 4% on average over time. Zhao et al. (2015) also examined the effectiveness of an eco-driving support system in a simulator environment. The system could provide both dynamic (voice prompts providing an instruction and a visual of the real-time CO_2 emission curves) and static feedback (i.e. a post-trip evaluation report including the fuel consumption rank, potential of fuel saving, and driving advice corresponding to the personal driving behaviour). A reduction of 5.37% for CO_2 emissions and 5.45% for fuel consumption was obtained.

Van de Vyver et al. (2018) focused on still another mechanism, i.e. self-interest. Based on an experimental design, drivers were shown one of three self-interest appeals (financial, health, kin) while waiting at a congested level-crossing site in the UK. Results showed that all three self-interest appeals increased the chances of drivers turning off their engines compared to the control condition.

Discussion & Recommendation for i-DREAMS

Performance monitoring and recognition based on in-vehicle technology, also referred to as OnBoard Safety Monitoring (OBSM) became popular in the period when Behaviour Based Safety (BBS) was one of the leading paradigms in the field of occupational health & safety management. BBS is an approach where principles drawn from behavioural science are applied to the management of industrial safety. The underlying rationale is that in order to reduce risk-related outcomes (like violations or road accidents), one needs to know the behaviours that lead to those risks, so that these can be changed. That however, requires those behaviours to be detected, for which it is required to monitor behaviour. All sorts of vehicle telematics and sensors allow behaviour to be observed unobtrusively during operations. Advances in data transfer and processing (Big Data analytics, deep learning, neural networks, et cetera) enable detailed information to be derived from raw data captured, almost in real-time. This information can be used to influence behaviours that need to change in order to improve road safety or eco-efficiency.

Three main intervention approaches in the field of performance monitoring and recognition were identified. The first approach, i.e. in-vehicle monitoring with information, derives the driver's current state in terms of performance on a selection of observed relevant parameters, and communicates this to the driver without putting information further into perspective. Several critical use parameters can influence the effectiveness of information. These range from quality, validity, and complexity, to detail, frequency, and control. There is actually no straightforward and consistent pattern that results from the available research that has concentrated on the impact of these critical use parameters on information effectiveness. Consequently, it is not always possible to recommend what is the best practice in terms of how to implement these critical use parameters.

It was observed that at some point in time, attention shifted to another approach, i.e. in-vehicle monitoring with feedback. The key-ingredient of feedback, is that it allows to assess a potential discrepancy between a present state on the one hand, and a hoped-for ideal state (or goal) on the other hand. In case a discrepancy is exposed, this triggers a corrective motivation that can result in different adaptation strategies (e.g. further pursue of the goal, revision or change of the goal, withdrawal from the goal, or denial of feedback received). Both theoretical and empirical research have identified a variety of critical use parameters that influence the effectiveness of feedback. One of the most comprehensive models in this regard, is the Eco-feedback Design Behaviour Framework by Sanguinetti (2018). Summarized, it contends that for feedback to be effective, it should be salient (i.e. it must attract attention), precise (i.e. it should trigger a learning process), and meaningful (i.e. it should induce the appropriate motivation). These feedback functionalities are primarily dependent upon three specific design features, i.e. information, display, and timing. Two remarks need to be made. First of all, the large majority of studies investigating the impact of feedback, is based on real-time use (i.e. feedback offered while driving), while there is a primarily interest in pre- or post-trip implementation of feedback. It is difficult to evaluate to what extent findings from real-time implementations of feedback can be generalized to the use of feedback in pre- or post-trip settings. Secondly, in line with what it was observed for the first approach (i.e. in-vehicle monitoring with information), there is no clear and consistent picture that emerges from studies that have examined the impact of information-, timing-, and display-related factors on the effectiveness of feedback. For some factors, results align a bit more, for others, results are inconsistent, or sometimes even not available at all. The only relationship that could be formally supported in the meta-analysis based on eco-driving studies by Sanguinetti (2018), was that length of intervention negatively associated with feedback effectiveness. In other words, the longer an intervention takes, the weaker will be the effect exerted by feedback. Notwithstanding, trends could be identified that aligned with the forwarded hypotheses, suggesting that feedback should best (1) be provided in multiple modalities, (2) include both fine- and course-grained information, (3) provide standards of performance comparison, (4) integrate game features (like points, levels or badges), and (5) be combined with other behavioural change techniques such as education and/or rewards contingent on performance. Despite the relevance of the design-related factors contained by the Eco-feedback Design Behaviour Framework, specialists working in the field of Feedback Intervention Theory and Goal Setting Theory have argued that for feedback to be effective, it is primarily important that feedback serves additional functionalities (i.e. feed-up, feed-forward, corrective motivation) on top of serving a purely informative purpose. Goals or feedback alone not necessarily activate the required self-regulatory processes targeted to realize the desired behavioural change.

This the reason why a third approach started to attract attention, i.e. in-vehicle monitoring with persuasive feedback. It was explained how persuasive feedback is indeed specifically aimed at reinforcing, changing or shaping attitudes or behaviors or both, but without using coercion or deception. In that sense, persuasive feedback indeed trespasses a purely informative functionality. Based on the Persuasive Systems Design (PSD) Model by Oinas-Kukkonen and Harjumaa (2009), it was revealed that persuasive feedback can actually serve four different functionalities, i.e. primary task support, dialogue support, social support, and system credibility support. Various gamification mechanisms can be implemented to realize primary task support, dialogue support, and social support. Primary task support for instance, can be achieved by means of so-called achiever mechanics, free spiritist mechanics, and general gamification mechanics like on-boarding, signposting, progress, flow, and time pressure. Dialogue support can be offered through implementation of reward mechanics, player mechanics, disruptor mechanics, and general gamification mechanics that try to create a personal connection such as a theme, a narrative, investment, or curiosity. Social support can be realized via the use of socializer mechanics or philanthropist mechanics. System credibility support is less related to principles of gamification, and more to principles like trustworthiness, expertise, authority, third-party endorsement, verifiability, and real-world feel.

Regarding the application of in-vehicle monitoring with persuasive feedback in the field of transportation, it was found that in the field of safety as well as in the field of eco-driving, attention went to testing the effectiveness of a variety of gamification-related principles (e.g. scores, competition, social pressure, incentives and rewards, penalties and loss aversion, tips and recommendations, personalization, self-interest, adaptive learning, et cetera). Two things are to be noticed. Firstly, quite a few studies examined the implementation of persuasive feedback in a real-time setting, while the primary interest is in implementation in a pre- or post-trip setting. As was the case with informatively used feedback, it is not clear to what extent findings based on real-time use of persuasive feedback can be generalized to the use of persuasive feedback in a pre- or post-trip setting. Secondly, altogether, results reported in studies reviewed, suggest there is potential in the application of persuasive feedback approaches in the promotion of safe and eco-efficient driving styles, although the variety in study designs and settings encountered, prevents the authors of this report from drawing firm conclusions as to what could work really well and what not. Most studies are exploratory, so more research is still needed to learn more about the critical use parameters to be considered and how to address these appropriately. Often, the effects of gamification mechanisms seem to be dependent upon the more precise way they are implemented, the context in which they are used, the behaviours being targeted, and characteristics of the persons exposed.

Throughout the next section, the focus will be on intervention approaches that fall under the third domain in the framework proposed by Mitchell et al. (2012), i.e. employee education and training.

2.8 Targeted factors for safety interventions

As described in the previous sections, interventions aimed at reducing risky driving behaviour. This can be achieved through several training, interactive knowledge, skill building sessions and warnings. These indications or warnings were targeted at multiple risk factors which were both conveniently monitored and crucial in reducing the probability of a collision or injury. Nevertheless, there is a distinction between factors targeted in real-time and those targeted after a driving session. This distinction is made in the next paragraphs, while Table 2 presents a summary of these targeted factors for both real-time and post-trip interventions.

Real-time interventions, are usually targeted at mental state such as fatigue, drowsiness, attention or distraction, stress, emotions or generally driver workload. In addition, in-vehicle feedback focuses on physiological measures like heart rate variability, skin conductance, skin temperature, breathing rate or electroencephalogram signals. Lane keeping, location of reckless events and safe distance to the vehicle ahead are also two important indicators that require real-time interventions. As it can be understood, the aforementioned factors can be efficiently monitored in real-time and the feedback aims at decreasing an imminent collision from happening.

On the other hand, post-trip interventions focus on improving overall driving behavior. Therefore, they are usually targeted at the frequency of harsh events (acceleration, breaking or cornering), distracted driving or other reckless events during rush hours or risky night hours, while particular concern is also given to eco-driving techniques.

Table 2: Targeted factors for real-time and post-trip interventions

	Real-time	Post-trip
Targeted factors	**Short-term monitoring**	**Frequency**
	fatigue (Lee and Chung, 2012; Bell et al., 2017; Fitzharris et al., 2017; Stephen et al., 2017; Aaron Huff, 2018; Arumugam and Bhargavi, 2019)	**harsh acceleration** (Toledo and Lotan, 2006; Donmez et al., 2008; Toledo et al., 2008a; Dijksterhuis et al., 2015)
	drowsiness (Lee and Chung, 2012; Aidman et al., 2015; Fitzharris et al., 2017; Balters et al., 2018; Arumugam and Bhargavi, 2019)	**breaking** (Donmez et al., 2008; Ando and Nishihori, 2012; Dijksterhuis et al., 2015)
	attention/distraction (Roberts et al., 2012; Bell et al., 2017b; Fitzharris et al., 2017; Stephen et al., 2017; Aaron Huff, 2018; Akerkar, 2018; Dehzangi et al., 2018; Paredes et al., 2018; Van der Heiden et al., 2018; Wong et al., 2019; Arumugam and Bhargavi, 2019)	**speed** (Toledo and Lotan, 2006; Donmez et al., 2008; Toledo et al., 2008a; Bolderdijk et al., 2011; Teng et al., 2011; Newnam et al., 2014; Dijksterhuis et al., 2015; Payyanadan et al., 2017; Tselentis et al., 2017)
	stress (Katsis et al., 2008; Paredes et al., 2018)	**steering** (Dijksterhuis et al., 2015)
	emotions (Katsis et al., 2008; Braun et al., 2019)	**eco-driving** (Toledo and Lotan, 2006; Ando and Nishihori, 2012)
	heart rate variability (Paredes et al., 2018)	**collision** (Donmez et al., 2008; Roberts et al., 2012; Payyanadan et al., 2017; Tselentis et al., 2017)
	temperature (Al-Taee et al., 2007; Lee and Chung, 2012)	
	lane keeping (Adell et al., 2011; Hasenjager and Wersing, 2018)	
	safe distance (Tulusan et al., 2012; Fitzharris et al., 2017; Li et al., 2017; Stephen et al., 2017; Aaron Huff, 2018b; Van der Heiden et al., 2018)	
	reckless events (Taubman et al., 2012; Zeeman and Booysen, 2013)	
	breathing rate (Balters et al., 2018)	

2.9 Acceptance of safety interventions

The use of safety interventions is constantly rising as increased effort is put into the development process of such information systems. Taking the determinants safety and anxiety into consideration, it was useful to investigate the acceptance of such technologies (Osswald et al., 2012). It is important to find out why drivers decided to use a certain information system as this intention could have a major impact on traffic safety. Being able to predict driver acceptance, which therefore includes usability and satisfaction aspects, would also be helpful in the automotive context to build appropriate in-vehicle technologies.

2.9.1 The definition and importance of acceptance

The adoption of a new in-vehicle safety technology could only be successful if the technology is effective in reducing the target risk and when it is also used efficiently by the driver. If the driver does not accept the technology, misuse or disuse of the technology is evident (Parasuraman and Riley, 1997). It is therefore important to reach a high level of acceptance and to measure the level of acceptance when developing or testing new vehicle safety technologies.

Acceptance is, however, a multifaceted concept and several approaches in literature have been proposed to define and measure acceptance (Adell et al., 2014). According to Adell (2009), acceptance can be defined as “the degree to which an individual incorporates the system in his/her driving, or, if the system is not available, intends to use it”. Hence, acceptance does not only relate to the degree of actual usage, but also relates to the intended use (e.g. in a purchase decision). Schade and Schlag (2003) therefore made a distinction between ‘acceptance’ and ‘acceptability’. According to them, acceptance is the result of the actual use of the system, and acceptability referred to the intended use. Similarly, according to Adell (2009), acceptance is associated with factors such as perceived usefulness, usability and ease of use, as well as intentions to use (and purchase).

A common ground in acceptance research is the notion that human behaviour is not primarily determined by objective factors, but also by subjective perceptions (Ghazizadeh et al., 2012). This implies that acceptance of in-vehicle technologies is based on individual attitudes, expectations and experience, obtained during actual use, as well as their subjective evaluation of expected benefits (Schade and Baum, 2007). The next sections will describe developed models of acceptance in more detail.

2.9.2 Psychological models of acceptance

Over the years, several psychological models have been developed in the literature to explain the determinants of acceptance (Zhang et al., 2019). Most of these models were not developed specifically for driver assistance systems, but were rather developed as acceptance models within the area of Information Technology. Although information technology and driver assistance systems share important features, there are also differences to take into account. The most important one of these differences is the time aspect (Adell et al., 2014), i.e. in vehicles there is typically only a very short time span available for the driver to make decisions and take actions, whereas in typical computer applications there is more time for cognition, decision and action. In some cases, even help can be requested during the execution of a task. These differences therefore need to be taken into account when evaluating the suitability of general technology acceptance models. These models are further described in the next paragraphs. For some of the models, such as Technology Acceptance Model (TAM), Theory of Planned Behaviour (TPB), Unified Theory of Acceptance and Use of Technology (UTAUT) and Unified Model of Driver Acceptance (UMDA), modified versions for driver assistance systems even exist.

2.9.2.1 Technology Acceptance Model (TAM)

One of the first and most widely used models to explain user acceptance of information technology is the TAM (Davis, 1989). According to TAM, which is depicted in Figure 16, actual use of the technology (system) depends on the user's behavioural intention to use the system, which in turn depends on the user's attitude towards the system. This attitude, in turn, depends on two user evaluations about the system, i.e. the Perceived Usefulness (PU) and the Perceived Ease of Use (PEOU). PU was originally defined by Davis (1989) as "the degree to which a person believes that using a particular system would enhance his or her job performance". PEOU was defined as "the degree to which a person believes that using a particular system would be free from effort". According to TAM, a higher perceived usefulness and perceived ease of use will have a positive influence on the user's attitude toward the system, which in turn will increase the chance of the driver actually using it. However, external background variables, such as age, gender, familiarity with technology, etc. may also play a role in people's attitude towards new technologies. The original TAM model has been continuously studied and expanded (Osswald et al., 2012).

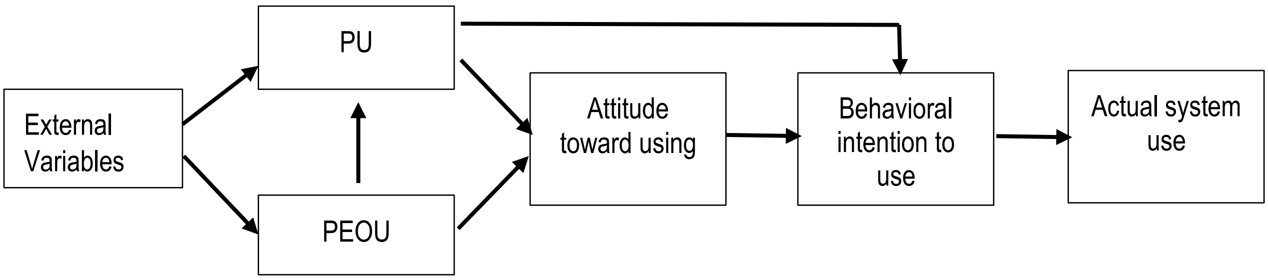

Figure 16: The Technology Acceptane Model (Davis 1989)

2.9.2.2 Theory of Planned Behaviour (TPB)

Understanding behaviour change in relation to the i-DREAMS system is important, as the purpose of the intervention is behavioural change. The i-DREAMS project will not be designed to take over vehicle control, and therefore the proposed intervention needs to result in driver behaviour change. In this respect it is important to consider models that aim to explain and predict behaviour change.

A general model to predict intentions and behavior is the model of TPB (Ajzen, 1991). The TPB was developed as an extension to the Theory or Reasoned Action (Fishbein & Ajzen, 1975, Ajzen & Fishbein, 1980), and has been widely applied as a method to understand a variety of behaviours. The TPB has been commonly applied in transport research to explain behaviours of drivers. Although the model was not originally developed to predict intentions and behaviour of technology as such, it has been used by many researchers to explain acceptance and usage of information technology (Legris et al., 2003; Venkatesh et al., 2003).

The TPB postulates that behavioral intention, the most central determinant of behavior, is determined by three conceptually independent variables: attitude, subjective norms and Perceived Behavioural Control (PBC), as shown in Figure 17. The attitude toward the behaviour is determined by beliefs about outcomes of performing the behaviour under study. Subjective norms, also called perceived social expectations, refer to the beliefs that individuals or groups have about behaviour. PBC, which is highly similar to Bandura's conceptualization of self-efficacy (Fishbein and Ajzen, 2010), refers to the subjective probability that a person was capable of executing a certain course of action. This variable influences behaviour both directly and indirectly.

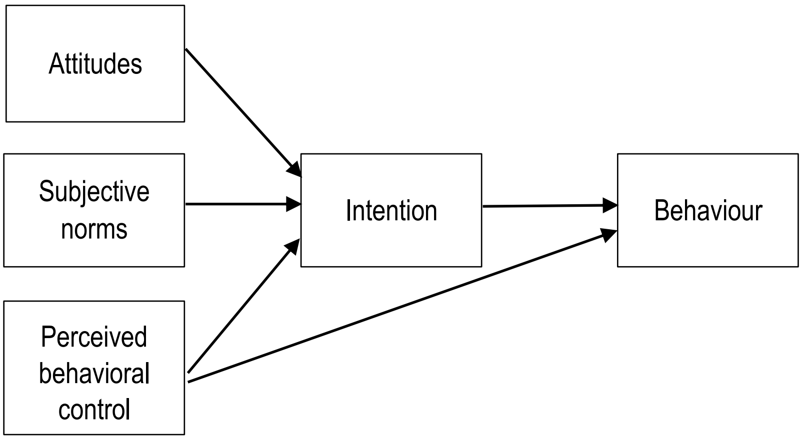

Figure 17: The Technology Acceptane Model (Davis 1989)

The TPB is based on the notion that by evaluating information available to them, individuals would make logical and reasoned decisions to engage in specific behaviours. The theory states that individual behaviour is determined by an individual's intention to engage in that behaviour, which in turn is influenced by the value the individual places on the behaviour, the ease with which it could be performed, and the views of significant others, coupled with the perception that the behaviour is under their control to perform. Therefore, according to the TPB, for the i-DREAMS intervention to be effective, the driver would need relevant and specific information, and the intervention would need to be easy to perform, be deemed as the 'norm' by significant others, and perceived to be within the drivers' control to perform.

However, the model has some limitations, which are important to consider. For instance, the TPB does not take into consideration other variables that factor into behavioural intention and motivation (e.g. threat, mood, past experience), or environmental and economic factors. The model also assumes that behaviour is a result of a linear decision-making process, not considering that behaviour can change over time. The time frame between intent and behavioural action is also not addressed.

2.9.2.3 Unified Theory of Acceptance and Use of Technology (UTAUT)

The UTAUT (Venkatesh et al., 2003) could be considered as a synthesis of several models of technology acceptance, including TAM and TPB. The UTAUT model, as shown in Figure 18, considers four main components of behavioural intention: performance expectancy, effort expectancy, and social influence, facilitating conditions, and four moderating factors: gender, age, experience, and voluntariness of use.

Performance expectancy refers to the extent to which the users believed that the system would help them to attain goals or gains. Effort expectancy refers to the degree of ease associated with the use of the system, while social influence refers to the degree to which the driver thought that other important people believe they should use the new system. Finally, several facilitating conditions, such as organisational or technical, may exist (or not exist) to support the use of the system.

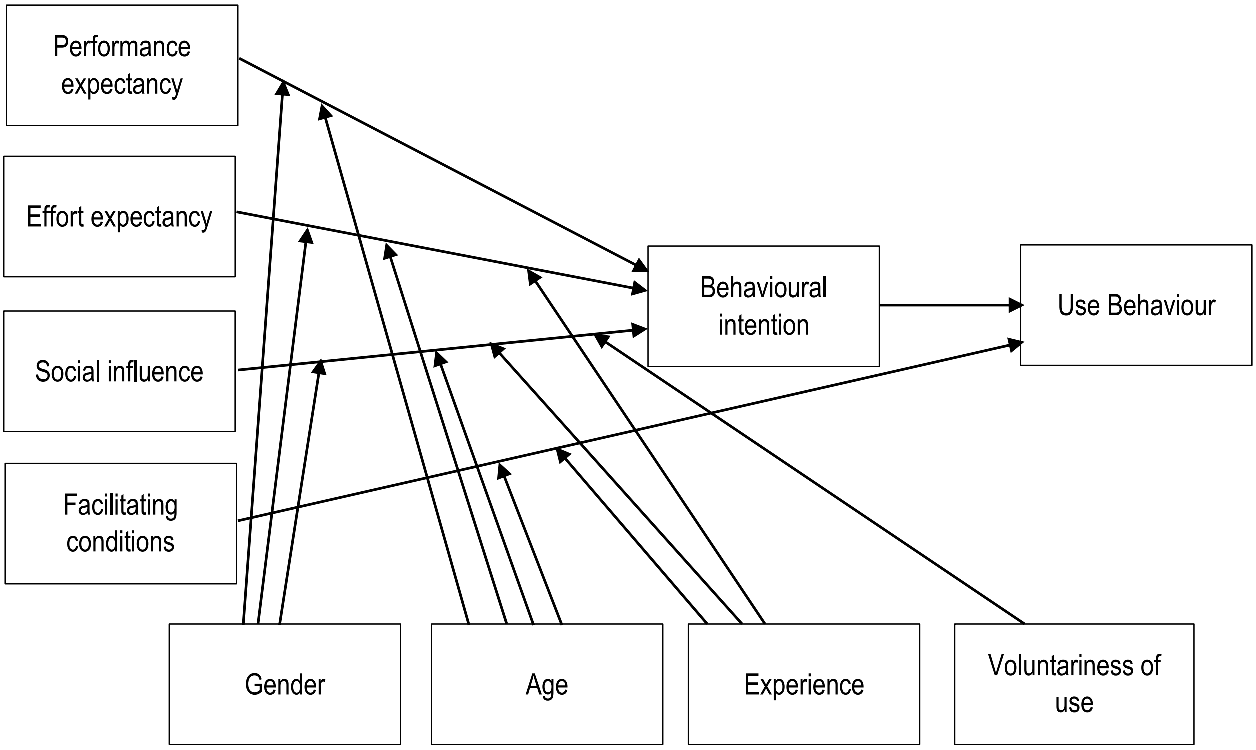

Figure 18: The Unified Theory of Acceptance and Use of Technology (Venkatesh et al., 2003)

2.9.2.4 Unified Model of Driver Acceptance (UMDA)

Another model integrating concepts from TAM, TPB and UTAUT is the UMDA by Rahman et al. (2018). The most important additions to the model (Figure 19), in comparison to the aforementioned models, are trust, endorsement, compatibility, affordability. Trust refers to the degree to which the driver has trust in the technology. Although it is included in the UMDA as a separate factor, in other works trust was modelled as the outcome of perceived usefulness and perceived ease of use (Ghazizadeh et al., 2012). Endorsement relates to the willingness of a driver to recommend the system to others (e.g. a loved one). It is believed that if the driver has a high intention to recommend the system to others, then this is an important indicator of acceptability. Compatibility refers to the extent to which the system aligns with the mental model of the driver. Especially in new advanced driver assistance systems, systems could surprise or conflict with the existing driver's mental model which could have a negative impact on acceptance of the technology. Finally, affordability relates to the cost of the system.

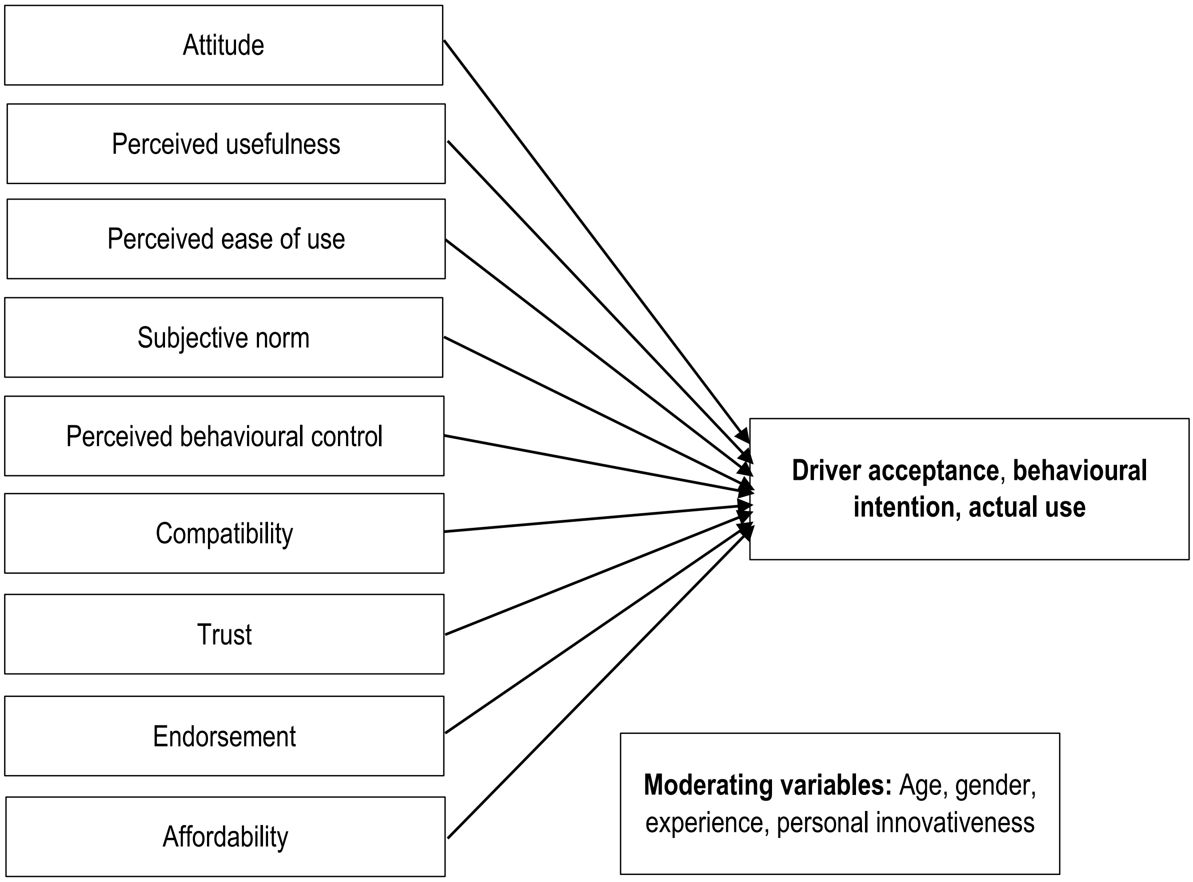

Figure 19: The Unified Model of Driver Acceptance (Rahman et al., 2018)

2.9.2.5 Transtheoretical Model of Change (TMC)

According to Prochaska and Velicer (1997), another model of behaviour change is the TMC. This model details the stages of behaviour change and assesses an individual's readiness to act on new, possibly healthier behaviour. TMC is widely used to explain how people initiate a change in behaviour, how they processed through the change, and how new behaviours are maintained. As shown in Table 3, the TMC consists of 6 stages: precontemplation, contemplation, preparation, action, maintenance and termination. The stages occur over time, and the pros and cons of changing, self-efficacy and temptation are important concepts in the model which occur at each stage. Individuals progress though stages in turn but may return to a previous stage before progressing. The model also argues that interventions aimed at promoting change should be designed to be appropriate for an individual's current stage.

Table 3: The stages of behaviour change as detailed by the Transtheoretical Model of Change Prochaska et al., 1998)

Stage	Description
Precontemplation	Identified as individuals who see no issue with current behaviour and are unaware of the problem
Contemplation	Individuals who are aware of the problem, and are aware of the desired behaviour change
Preparation	When an individual intends to take action
Action	When an individual engages or practices the desired behaviour
Maintenance	Consists of an individual working to sustain the behaviour change
Termination	This is the stage where individuals have 100% self-efficacy and express no temptation to return to their former behaviour. However, this stage is not always necessary to successfully change a problem behaviour

According to the model, in order for the i-DREAMS system to be successful, individuals would first need to be aware of the problem behaviour as well as the desired behaviour change. This information could be provided from the i-DREAMS system in the context of real time warnings and personalised after trip feedback. The feedback would also help an individual move through the preparation stage and into the action stage, to engage in behaviour change. The system would then assist helping an individual sustain behaviour change through real time warnings, interventions and feedback, to ensure drivers remain in the safety tolerance zone. The TMC had some limitations to consider. The model has traditionally been used to explain changes in health behaviours. It also fails to explain how individuals could change their behaviour with apparent suddenness. Furthermore, it has also been criticised for having arbitrary boundaries between the stages, and assumes that individuals made coherent and stables plans, particularly in relation to behaviour change. Finally, the model ignores the role of reward and punishment in relation to developing habits and changing behaviour.

2.9.3 Crucial factors affecting intervention acceptance

Based on a synthesis of different literature resources on acceptance and acceptability of new technologies and the overview of the different psychological models of driver and technology acceptance, a synthesis of different categories of variables can be identified influencing acceptance of new in vehicle technology and is presented in the following subsections.

2.9.3.1 Socio demographic factors

Several factors such as age, gender, income, educational level, previous accident involvement and place of residence can be identified as potentially influencing factors for acceptance. For instance, although findings were not always consistent in literature, young male individuals with higher income and education levels, who were more technology savvy, living in urban areas have higher levels of acceptance with respect to new technologies (Bansal et al., 2016). Also previous crash involvement tended to increase the acceptance of new in-vehicle technologies.

2.9.3.2 Psychological factors

A wide range of psychological factors had a potential impact on acceptance of new in-vehicle technologies. Some of them were more distant factors, such as general attitudes and trust toward new technologies, i.e. the position on the technology adoption curve, where it has been shown that early adopters of technology in general were more willing to accept new Advanced

Driver Assistance Systems (ADAS) technologies (Kaur and Rampersad, 2018). Also knowledge, attitudes and beliefs of the driver with respect to the target risk played an important role in the acceptance of technologies aiming to reduce that target risk, i.e. if a driver did not consider the target risk as a real problem, or the driver did not feel vulnerable to that risk, then a system aiming to reduce the target risk would not be considered as important for the driver, and acceptance would be low.

More specific psychological determinants of acceptance related to actual system itself also exist. For example, the driver's knowledge about the system: if the driver didn't know about the benefits and limitations of the system, it could lead to a wrong evaluation of the system by the user. In general, previous experience with or exposure to the system would help to increase the level of knowledge about the system. It is known that new in-vehicle systems typically have a learning curve. Hence, the knowledge, evaluation and acceptance by the user could be very different before and after use of the system. This is closely related to the concept of **trust** in the system, where a distinction needs to be made between initial trust and dynamic trust. Initial trust refers to the evaluation by the driver on how the system would help the driver to reach goals in a situation characterized by uncertainty and vulnerability, whereas dynamic trust refers to the same evaluation after having the opportunity to experience or use the system. Trust is also sometimes conceptualized as the result of perceived usefulness and perceived ease of use (Ghazizadeh et al., 2012).

Perceived safety (i.e. the feeling that the in-vehicle system would help the driver to increase personal safety) has also been found to be crucial .(Zhang et al., 2019; Zoellick et al., 2019) Research found that systems that presented alerts in situations that drivers also considered as 'alarming', received higher acceptance, even if the driver would have been able to avoid the incident without the warning (Källhammer and Smith, 2012). This is reflected in the concept of risk perception. Acceptance is usually higher when the system warned the driver in situations where personal perception of risk was also higher, but such a scenario does not necessarily mean that the actual risk of a collision was higher (Sheridan, 2008).

Zhang et al. (2019) also identified the user's performance expectancy with respect to the system and perceived privacy risk as potential psychological factors for acceptance. Performance expectancy related to the extent to which the user thought that the system would help him to achieve goals. Perceived privacy risk originated from the possibility that travel data or behavioral data from using the system could be transmitted to the government, vehicle developers, and insurance companies without notice, be used against the users or be hacked by others (Zhang et al., 2019).

Perceived usefulness, perceived cost-benefit and perceived ease of use have been described already as important determinants in the formation of the driver's attitude with respect to a new in-vehicle system, and ultimately also in the acceptance of the system. Perceived usefulness relates to aspects such as the perceived (in-)effectiveness and reliability of the system. However, a high perceived usefulness does not necessarily imply a high satisfaction or acceptance of the system: if the system didn't work well (e.g. it was confusing or irritating), the driver would try to ignore it. Perceived usefulness and performance expectancy could also not be evaluated without taking the cost of the system into account. When the perceived cost-benefit ratio is considered weak, the user would not be willing to purchase the system. Perceived ease of use relates to aspects such as how pleasant the system was to use or to the level of effort needed by the driver to use the system.

Finally, social influence could also play a role in the level of acceptance of an in-vehicle system. If other important people or relatives perceive the system to be important, then the driver would be more inclined to believe in using the system.

2.9.3.3 Design and system characteristics

Specific design or system characteristics of the in-vehicle system could influence the way how the driver would perceive the system and determine its acceptance. For instance, a system needs to be visually attractive (Kim and Moon, 1998; Fogg et al., 2003; Weinstock et al., 2012) and the configuration of warnings such as visual, acoustic or haptic, needs to be designed in a way to avoid irritation, unless in critical situations where immediate reactions from the driver are needed. It was also found that systems that generate undesired feedback or have certain functional limitations (e.g. work only under certain operational conditions) were less accepted by the driver. Finally, the timing of warnings play a crucial role in the acceptance of in-vehicle warning systems. Warnings that were triggered too early generated false positives with the risk that, under repeated exposure, warnings would eventually be ignored, whereas warnings that were generated too late, would provide less time for the driver to react and may create ineffective warnings under real safety risks.

2.9.3.4 Trip related characteristics and habituation

Finally, it was found that time pressure (Techer et al., 2019) during a trip can lead to warnings being ignored or the system being switched off, leading eventually to a lower system acceptance. Also habituation due to repeated exposure of warnings by the system led to reduced effectiveness (Warner and Aberg, 2008).

2.9.4 Measurement of acceptance

The overview of findings from the literature in the previous section showed a range of categories of factors influencing acceptance and acceptability of a new in-vehicle system. The question therefore is how to measure acceptance and its determinants in order to evaluate the potential of a new in-vehicle systems. Most of the evaluations of acceptance were based on focus groups, surveys (i.e. subjective ratings) or the observation of drivers while using the system.

2.9.4.1 Survey instruments techniques

Several studies propose standardized survey scales to measure aspects of acceptance. One of the first survey instruments was developed by Van Der Laan et al. (1997) and focuses on the dimensions of system usefulness and satisfaction. The authors used a questionnaire consisting of nine 5-point rating scale items, as shown in Annex B.

2.9.4.2 Observational techniques

Besides the variety of survey instruments to measure acceptance, the actual use of the system measured by means of behavioural outcomes could also reveal aspects of acceptance by the user. For example, brake reactions (e.g. brake response time or maximum brake force) could reveal if the timing of warning signals was appropriate in case of advance collision warning, or steering response time in case of lane departure warning. In an automated driving context, recent research focused on support system disengagements (Wang and Li, 2019) as a measure of how confident the driver was with using the support system. Frequent system disengagements could be an indicator of perceived unreliability of the system.

2.9.5 Discussion and Recommendation for i-DREAMS

User acceptability and acceptance are crucial concepts to evaluate in the design and evaluation stage of the i-DREAMS platform. In order to maximize future acceptance by the driver, it is therefore crucial to include the input from drivers as early as possible during the design stage of the i-DREAMS system. i-DREAMS should therefore closely interact with potential users and evaluate prototype intervention technologies (e.g. by means of a user centered design approach). Once in-vehicle interventions are implemented and operate in the simulator experiments and the field trials, i-DREAMS should evaluate different facets of user acceptance, preferably using both survey and observational techniques.

Research has also shown that the evaluation by users of a new system depends on their understanding of the possibilities and limitations of the system, as well as their experience by using the system. Users often have to ‘learn’ how to use a new system. Hence, it was considered important to educate drivers and operators on how to use the system. i-DREAMS should therefore also provide documentation and educate drivers about the benefits and limitations of the developed system. Finally, research has shown that acceptance of in-vehicle systems increased when drivers were given feedback on why alerts were given, even if these alerts were not always considered necessary by the driver at the time when they were triggered (i.e. false positive). Post-trip feedback could help to explain to drivers when and why certain warnings were given by the system and as a result, increase overall system understanding and acceptance.

2.10 Performance of safety interventions

Given the safety risks that are usually linked with the application of a real-time warning system, the warnings should be designed carefully to ensure optimal performance of the system. This performance heavily depends on acceptance of the system by the driver. A poorly designed system might cause reduced acceptance and thereore effectiveness because interventions were perceived as not relevant or simply annoying for a specific situation. This results in the driver losing confidence in the system, or even completely turning off or sabotaging the system.

The design process requires extensive testing of different options for modality (auditory, acoustic, haptic), warning presentation method (HUD, speech), warning message (specific vs non-specific, frequency of beep tone) and warning thresholds (TTC, headway time). The function of the application (e.g. FCW, drowsiness detection, blind spot) should be considered. Each intervention has an underlying behavioural change mechanism (informing, warning, motivating, nudging) that is linked with the specific application. The aforementioned aspects of in-vehicle technologies are discussed in the next subsections.

2.10.1 Modality

Warning modality usually refers to the human sensory mechanism used to receive the warning. The most commonly used modalities are visual, auditory and haptic. Each modality had its own specific advantages and disadvantages. For example, visual warnings could easily be displayed to the driver with existing technologies. They could also contain specific information that does not require a lot of processing time for the driver icons (Cao et al., 2009). As driving is already a very visually demanding task, visual warnings might create overloading of the drivers' visual capabilities (Ho et al., 2006). Visual warnings are less intrusive than auditory or haptic warnings and might remain unnoticed when not immediately within the drivers' field of view (Lylykangas et al., 2016a). Visual warnings could potentially be enhanced by making them "blink" in the drivers' peripheral vision, which would cause the driver to notice them quicker (Cao et al., 2009).

Auditory and haptic warnings are more intrusive, thus better suited to grab the driver's attention (Ho et al., 2006). But they might also be "short lived", meaning that information might quickly be forgotten by the driver. Another disadvantage is that this increased level of intrusiveness also creates the risk of startling the driver (Baldwin and May, 2011; Naujoks et al., 2019). Triggering too many intrusive warnings in non-critical situations would cause annoyance within the driver and reduce acceptance of the system.

Tactile warnings are only effective when the driver is in physical contact with the actuator. When driving, the driver already is subject to all kinds of vibrations caused by road conditions and other external factors. The tactile message should carefully be designed to make sure it stood out of any present noise. This is similar to auditory messages, because the auditory noise that is present in a driving environment, could cause the auditory message to become "muted" (Ryu et al., 2010; Murata et al., 2017).

Mohebbi et al. (2009) investigated the effects on brake response time for auditory (monotonous 2000Hz tone) and tactile (vibrotactile seatbelt) warnings during 3 types of secondary task (cell phone conversation; none, simple, complex). The results showed that reaction time was quicker for tactile warnings compared to auditory warnings. Other studies also showed that especially in a noisy environment and for situations where the driver was engaged in activities that work on the auditory sensory channel, haptic warnings showed the best results (Murata et al., 2017). Similar results were achieved in another study (Biondi et al., 2014). They found that brake reaction time was slightly shorter when using tactile warnings instead of auditory warnings. Even better results were achieved by using a multimodal warning (combination of auditory and tactile).

Lylykangas et al. (2016) compared the effect of brake reaction time, between visual warnings (blinking light in windscreen) and haptic warnings (vibrating throttle pedal). They found that brake reaction time was similar for the haptic warning and the combination of haptic and visual warning. Both haptic and the combination of haptic and visual warnings were found to be quicker compared to the visual warning. On a subjective scale, the multimodal warning was rated highest for noticeability. Another study showed that there was a link between cognitive capabilities of the visual and auditory sensory channels and that this link might create "inattentional deafness", a phenomenon where auditory cues might be missed by the driver in visually demanding situations like driving (Macdonald and Lavie, 2011). Given that haptic warnings used another sensory channel; this suggest that it could be beneficial to use haptic warnings in visually demanding situations (Chun et al., 2012).

Experiments showed there were potential safety benefits for a system where the choice of modality was based on driver workload. A such system was the Adaptive Multimodal in-Vehicle Information System (AMiVIS) by Park and Kim (2015). This system monitored driver workload and based on these measurements, the most appropriate modality to limit the workload was selected. The AMiVIS system also filtered information and decided what information should be shown at which time. For instance, when the workload was high, the system could decide to only display the most critical information. In safety critical situations, a multi-modal warning should be used (Cao et al., 2009). Effects of "Redundancy gain" for multimodal systems have been found in multiple studies (Liu and Jhuang, 2012; Naujoks et al., 2019). Subjective rating and acceptance was also rated highest for multi-modal systems in the context of pedestrian warning (Large et al., 2019).

2.10.2 Thresholds

Choosing a threshold value is a very important aspect of creating a performant warning strategy. The thresholds setting would always be a trade-off between early warnings or late warnings. Early warnings provide plenty of time for the driver to anticipate the situation, but also hold the risk of generating false-positive warnings which distracted the driver from the primary driving task (Ho and Spence, 2005) and reduced the acceptance of the warning system (Lee et al., 2002; Winkler et al., 2016). Late warnings, on the other hand, create less false positives, but might place the driver in a situation where it is already too late to anticipate.

Multiple strategies to define thresholds value are possible. For collision warning, two main approaches could be distinguished (Bella and Russo, 2011). The kinematic approach is based on the laws of motion. In this approach, the hypothesis of maximum deceleration, reaction time and current vehicle state is combined to determine a minimum stopping distance, when the current distance is less or equal to this minimum distance, the warning would be triggered. When using the kinematic approach, it is very important to consider brake reaction time. Experimental studies showed that brake reaction time for surprise warnings should be considered to be in the interval 1.18s – 1.52s (NHTSA, 1999).

The perceptual approach is based on exceedance of Time-To-Collision (TTC). This approach is much more simplistic, due to the fact that TTC is widely used as a measure to define crash risk. However, the effectiveness of both approaches need extensive testing because human perception and reaction time are often the crucial factor in the design of an effective warning strategy. Multiple studies have focussed on this topic. Yan et al. (2015) found that TTC thresholds value of 4.0s– 4.5s were an ideal trade-off for warnings in the context of a collision warning system. This is similar to TTC values found in the application of red-light-running warnings. Zhang et al. (2019) showed that collision rate was lower when verbal auditory warnings were triggered at a 3.5s – 6s headway time to a collision situation where the view was obstructed. Yan et al. (2014) found that collision rate was lower for early warnings (5s) compared to late warnings (3s). Both studies found that a TTC value of 2s - 2.5s was the absolute minimum to provide enough response time for the driver.

Drivers have been found to subjectively prefer being informed early of possible risks, but in a non-intrusive manner (visual). Early warnings are also generally associated with a greater safety margin (Large et al., 2019). It was also found that the preferred timing depended on situational influences, for example if the velocity of the vehicle in front was lower, drivers preferred to be warned earlier (Werneke and Vollrath, 2013; Winkler et al., 2016).

2.10.3 Presentation Method

The presentation method depends on the actuators that are available in the vehicle or intervention system. These actuators could be a head-up-display, steering vibrator, surround system etc. Choosing the right presentation method refers to "where" the message is given to the driver. This aspect is important because the reactions that are demanded from the driver should be intuitive to the warning (Ho et al., 2006; Meng et al., 2015). If the driver's attention is already drawn towards the danger by the warning, the effectiveness of the warning will be higher (Ho and Spence, 2005). The presentation method should also ensure that the warning successfully reached the driver. For example; a blind spot warning usually is displayed in the rear-view mirror because this is where the drivers' gaze would be when checking the mirrors to change lanes.

This example of a traditional blind-spot system could potentially be enhanced by turning it into a multi-stage, multi-modal system. A second stage would present in cases when the driver does not see the visual warning in the mirror and initiates a lane-changing manoeuvre. A more intrusive auditory or haptic warning could then be triggered. Chun et al. (2013) investigated the presentation method for a haptic warning within the context of a blind spot warning system. They found that in terms of collision avoidance a vibrotactile warning through the steering wheel was more effective than a vibrotactile warning through the seatbelt. A similar study, with similar results, was conducted for the application of forward collision warning (Chun et al., 2012). They also compared haptic warnings through the steering wheel to haptic warnings through the seatbelt. Reaction time, collision avoidance and subjective usefulness were found to be better for warnings through the steering wheel. Another study went even further and found that the haptic warning could be enhanced in terms of brake reaction time by using both steering wheel actuators and actuators on the torso to create a "towards driver" effect (Meng et al., 2015).

2.10.4 Warning Messages

The warning message should be chosen carefully according to the warning situation and risk level. A study was performed where the effect of visual symbols was examined in the context of forward collision warning (Winkler et al., 2018). They concluded that for time critical situations a non-specific symbol that prompted direct action (Stop-sign) gave the best results for reaction time. For situations where time was not critical, a more specific symbol that depicted the type of danger was more effective than non-specific symbols. For most warnings and especially those that didn't prompt direct action, the driver still wanted to visualize and judge the danger themselves (Yan et al., 2015). This process could be accelerated if the drivers' attention was already drawn towards the danger by the warning message, providing better situational awareness (Liu and Jhuang, 2012; Schwarz and Wolfgang, 2017; Zhang et al., 2019c). The warning message should be specific, containing more information, as long as the situation was not time-critical. This should help the driver to get an improved situational awereness. For situations that were time-critical, warnings should not be specific. By using simple messages, mental workload of the driver could be reduced which allowed timely action. One study showed that collision rate increased when specific warnings instead of unspecific warnings were used in time-critical situations (Yan et al., 2014).

Speech messages are an example of warnings that are very useful to communicate detailed information to the driver (i.e. navigation system), but should never be used to communicate critical information. Noise, or other verbal activities, such as radio or passenger conversation might cause confusion, misunderstanding and masking (Ho and Spence, 2005). Similar results were found for visual warnings, where it was found that the interpretation of icons was quicker than written text (Cao et al., 2009). Because of the high intrusiveness, auditory or haptic warnings could be very useful for recapturing the driver' attention in safety critical situations like forward collision warnings. For safety critical situations, the message should not be specific, but the design should be intuitive and compatible with any possible present noise

(Murata et al., 2017). Moreover, Fitch et al. (2011) showed that when the number and specificity of tactile warnings increased, brake reaction time decreased.

Simulator studies have been performed to find which auditory tones were most effective to warn drivers in the context of a forward collision warning. They showed that for a pulsating sound, a frequency that was too high (641Hz), was less effective because for the driver it didn't appear to be a warning sound. To be effective, the intensity, expressed as duty cycle (time active during a given time interval) of the pulsating warning should also be high enough. A duty cycle of 25% was found to be too low. Instead a duty cycle of at least 50%, combined with a frequency of 234Hz – 319Hz was shown to be more effective in terms of collision avoidance, brake reaction and subjective rating (Wu et al., 2018). For speech messages, the perceived urgency of the message depends on the chosen words (Hellier et al., 2002). For example, the word "danger" was perceived as more urgent than the word "note". Further research showed that in terms of efficacy for collision warning systems, the urgency of the chosen word interacted with the loudness of the message. The combination of the more urgent word "danger" at 70dB and combination of the less urgent word "notice" at 85dB were found to be more effective than the combination of the more urgent word "danger" at 85dB, which likely caused startling of the driver and showed similar collision rates to no warnings at all (Baldwin and May, 2011).

2.10.5 Discussion and Recommendation for i-DREAMS

Based on this literature review, it seemed that the best warning strategy would be a multi-stage, multi-modal strategy as visually illustrated by Figure 20. By specifying multiple stages, warnings could be adjusted to each specific stage. Literature showed that it was beneficial for drivers to be informed early, but in a non-intrusive way. By using visual (non-intrusive) and detailed messages in the first stage, the driver has all the information available. When the driver is not adapting to the situation, the parameter that is used to define thresholds would change until a threshold value was passed that triggered a second stage. In a second stage, the warning could be made more intrusive by adding auditory warnings and/or making the visual warning blink. In a third stage, immediate action from the driver would be required, and at this point warnings should not be specific at all and should be intrusive (without startling the driver) to immediately capture the drivers' attention or even trigger an intuitive reaction from the driver. At all times, information or warnings should be presented in an intuitive way that does not overload the drivers' cognitive abilities.

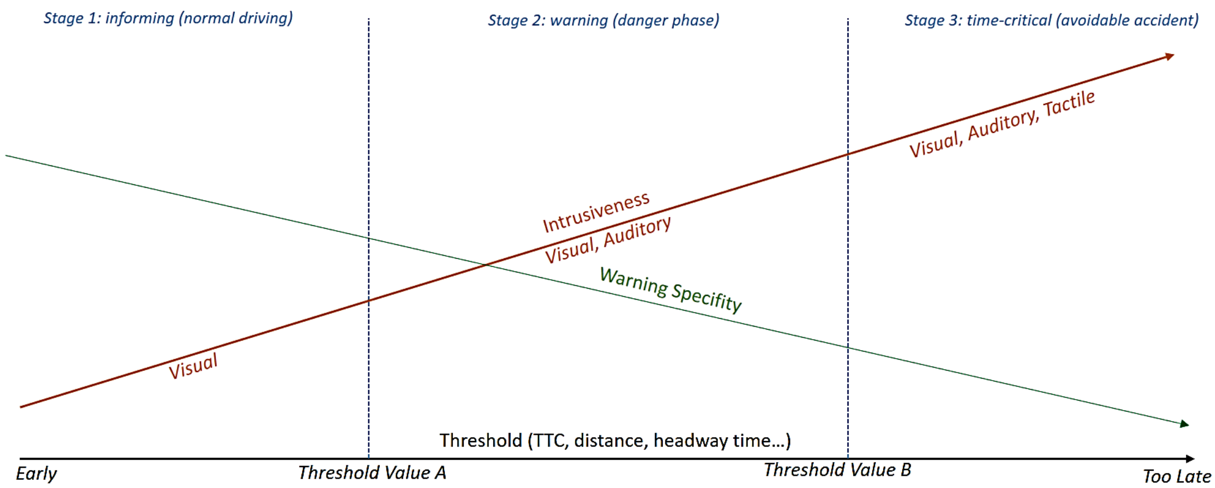

Figure 20: Illustration of the proposed warning strategy

2.11 Conclusions regarding the i-DREAMS system

The results of the literature review indicated that the most reliable factors targeted for real-time interventions are fatigue, drowsiness, attention or distraction and for post-trip interventions are speed, harsh accelerations and braking. It was also releaved that user acceptability and acceptance are crucial concepts to evaluate in the design and evaluation stage of the i-DREAMS platform. Research has also shown that acceptance of in-vehicle systems increased when drivers were given real-time and post-trip feedback. By specifying multiple stages, warnings could be adjusted to each specific stage. Literature showed that it was beneficial for drivers to be informed early, but in a non-intrusive way. Lastly, information or warnings should be presented in an intuitive way that does not overload the drivers' cognitive abilities.

3 Review of real-time interventions

This section provides an overviews, compares and contrasts the technology utilized for real-time feedback as well as its utilization in recent literature studies. The possibility for after-market installation is also discussed, as it is important to know what technologies could possibly be installed as part of i-DREAMS. Technologies are distinguished on their modality and are assessed based on their acceptance and effectiveness.

3.1 Overview of technological approaches for real-time interventions

Within the domain of advanced assistive in-vehicle technology or 'ADAS', a distinction can be made between different approaches, in function of three factors, i.e. message modality, message timing, and message functionality. Message modality refers to the sensory mode that is used to communicate with the driver. In the literature, several basic sensory modalities have been identified and studied, going from visual (e.g. Schwarz and Fastenmeier, 2017; van der Heiden et al., 2018; Hajiseyedjavadi et al., 2019; Karjanto et al., 2019; Schewe and Vollrath, 2019), and auditive (e.g., Bazilinskyy and de Winter, 2017; Murata et al., 2017; Schoemig et al., 2018; Wu et al., 2018) to vibro-tactile or haptic (e.g., Murata et al., 2018; Benloucif et al., 2019; Cohen-Lazry et al., 2019), and thermal (e.g. Schmidt and Bullinger, 2019). Sensory modalities can also be used in combination (e.g. Ho and Spence, 2008; Jakus et al., 2015; Lylykangas et al., 2016; Biondi et al., 2017; Geitner et al., 2019). Some in-vehicle systems are even capable to dynamically adapt the sensory modality in function of how much workload is imposed on the driver. As explained by Park et al. (2015), this is called adaptive multimodal interaction. An adaptive multimodal in-vehicle system is able to reduce a driver's workload by selecting an appropriate sensory modality.

In-vehicle assistive technologies can also vary in terms of message timing. Message timing relates to the moment at which warnings or instructions are communicated to the driver. Here as well, a distinction can be made between adaptive and non-adaptive systems. As stated by van Gent et al. (2019: p. 204), in combination with driver monitoring systems, it becomes possible to monitor a driver's state and make inferences about which signals, warnings or instructions a driver likely can or cannot safely handle. As such, at any moment where the generation of a message might exceed safe levels in terms of imposed workload, the system might decide not to display the message, retract it, or recommend termination of the execution of the message.

Additionally, in-vehicle assistive technologies can vary in function of the targeted functionality (see the ADAS&ME-project for an overview: www.adasandme.com). Overall, seven different functionalities can be identified in the literature:

A first category of systems only provides a warning or information, without any intervention by the technology taking place. According to Huang et al. (2005: p. 279), information or warning provided to the driver can either relate to driver state (e.g., driver alertness monitor, physiological measures, breathalyzer), or to certain aspects of the driver task. As for the latter, a further distinction can be made between systems that provide a warning or information at the level of (1) control-related tasks (e.g. a lane departure warning-only system), (2) guidance-related tasks (e.g. collision warning system), and (3) navigation-related tasks (e.g. vehicle and cargo tracking system).

A second category of systems only provides persuasive feedback related to the driver state and/or the driving task without any intervention by the technology taking place. As explained by van Gent et al. (2019), this type of system offers the following functionalities: primary task support, dialogue support, social support and system credibility support. Each of these functionalities in turn, are implemented by means of a specific set of gamification mechanisms (see Figure 21). These different persuasive functionalities and their respective gamification mechanisms are explained in detail.

A third category of systems provides a warning with the potential of an intervention by the technology taking place. These systems can apply to the driver state, or to the driving task (i.e. control-related, guidance-related or navigation-related). Possible examples are, fatigue detection systems triggering emergency brake if there is no reaction from the driver to the warning signal (i.e. a driver-state related example), collision warning systems with a pre-emptive brake assist functionality, or intelligent speed adaptation (i.e. driver task related examples).

A fourth category of systems intervenes in the control of the vehicle without initiation by the driver. These systems typically apply to driving task-related aspects. Examples are electronic stability control, brake assist systems, adaptive cruise control, or adaptive headlights.

A fifth category of systems is aimed at the prevention of high-risk behaviours. That can be for instance, seat belt reminders, alcohol ignition interlocks, teen driver support systems, or a smart licence car key.

A sixth category of systems is specifically targeted at vulnerable road user protection. Possible examples are collision warning systems detecting pedestrians and cyclists and providing warnings or automatic braking to reduce impact speed. Or, active bonnet lift systems which work by raising the bonnet of a vehicle to provide space to absorb the impact energy, specifically, of the pedestrian's or cyclist's head. Such systems are triggered by a sudden force on the front bumper.

Finally, the category of post-crash systems is presented, such as accident data recorders or emergency crash assistance systems.

Figure 21 gives an overview of the aforementioned approaches.

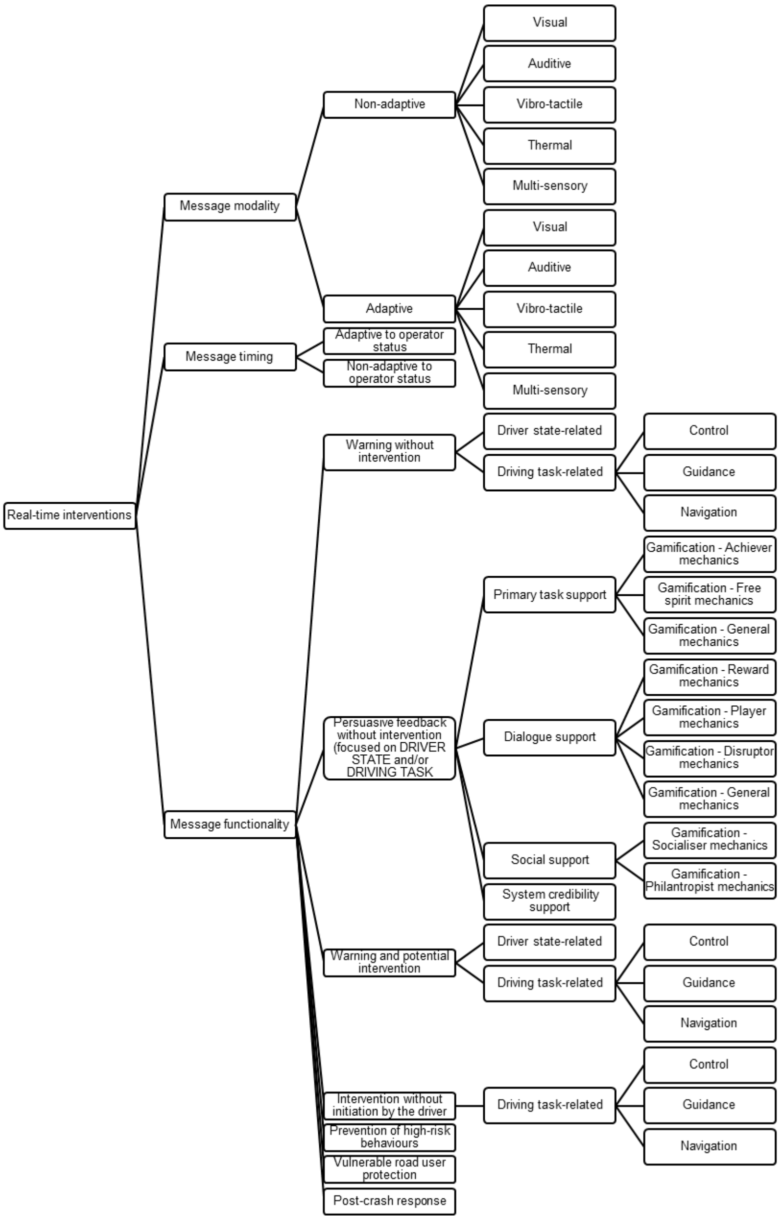

Figure 21: Technological approaches for real-time interventions

When assessing the number of commercial vehicle registrations it becomes evident that buses are accountable for a relatively small fraction of the vehicle pool (Embargo and Gmt, 2016). For instance, in Europe, for each new operating bus there are more than 9 heavy duty goods vehicles (Embargo and Gmt, 2016). Additionally, a critical analysis of the data regarding road safety incidents and resulting deaths and morbidities evidences that these, even when normalised by the travelled distance, are far smaller for the case of buses when comparing with the remaining road modes (ERSO, 2016; ERSO, 2018; European Commission, 2018, 2019). Nonetheless, since the purpose of buses and coaches is to enable the mobility of predominantly human beings, their (road) safety is of the upmost relevance.

For obvious reasons, buses and trucks present relevant similarities and difficulties. Often these vehicles also share mechanical components and in both cases drivers are regularly exposed to demanding social and physiological work environments. Hence, it is not uncommon for EU regulations and directives to make compulsory the deployment of similar or comparable assistance and safety technologies for all heavy duty vehicles, regardless their purpose is to carry passenger or goods.

However, when discussing safety or advanced driver assistance systems it is important to distinguish between urban and intercity environments, i.e. between buses and coaches, as these different contexts pose distinct challenges to driving and drivers. Coaches mostly link distant urban centres and spend most of their journey on motorways or other secondary but relatively high speed roads. Furthermore, although less often than in trucks, it is not uncommon for drivers to travel long journeys without passengers. Therefore, intercity and touristic coach drivers generally face safety concerns similar to the ones experienced by truck drivers. Contrarily, buses and respective drivers that operate within urban environments face quite distinct safety related interactions. In particular, the interaction between buses and vulnerable road users, i.e. pedestrians and cyclists, low speed collisions, with both moving and stationary obstacle, and other incidents resulting from passenger-driven distractions are the most commonly identified challenges.

When evaluating both the literature and available commercial solutions it is often possible to clearly differentiate OEM and aftermarket systems. The former tend to provide active systems that evaluate driving context and react in real-time, autonomously controlling the vehicle actuators. Many of such solutions were firstly introduced as optional equipment that later became mandatory and enforced by law and regulations applicable to the homologation of new vehicle types. Conversely, aftermarket solutions are mostly restricted to passive driver assistance systems and not all provide actual real-time feedback to drivers. Additionally, while aftermarket systems address and evaluate the usage of safety related systems, such as service and secondary brakes, numerous products are almost exclusively focused on eco aspects of driving, where eco stands for both ecological and economic efficient driving, even if safety and efficient driving are often closely correlated (Boodlal and Chiang, 2014; Department for Transport, 2016; Scott and Lawson, 2018; Energy Saving Trust, 2019; FMCSA, 2019).

There is a large number of passive and active safety systems that can be classified as advanced driver-assistance systems (ADAS). As such systems become standard and on-board/in-vehicle systems and technical capabilities evolve some ADAS become perceived as a commodity and are currently seldom regarded as an ADAS. The assistance systems most commonly deployed by OEM in buses and coaches are described in the Annex C.

3.2 Technologies utilized in real-time interventions

While the use of hand tools and equipment as well as other web-based platforms and devices is naturally accompanied by multisensory real-time feedback, visual, autitory and haptic and multimodal technologies are elaborated. The aim of this section is to identify the real-time feedback strategies within or between the visual, auditory, and haptic modalities, either in isolation or in combination.

3.2.1 Visual

3.2.1.1 Dashboards

Dashboards are widely used for presenting information to the driver. Most dashboard displays are digital displays that could offer different types of information like text, icons, visual scales, maps or even complete situations could be presented as depicted in Figure 22. Hence, dashboards are a versatile tool for presenting detailed information to the driver. However, because the dashboard is already used for a large amount of information, not all new information is immediately received by the driver. The dashboard is usually located below the driver's viewpoint, meaning that the driver needs to look down and off the road to read the information on the dashboard. Altogether, a dashboard is useful to present detailed, but non-critical information to the driver. In the context of an aftermarket system, dashboard displays cannot be used, as they are pre-configured by the manufacturer.

Figure 22: Dashboard display Peugeot 3008 (Peugeot, 2017)

3.2.1.2 Head-Up Display (HUD)

Originally developed for military applications like fighter jets, head-up displays have found their way into mass-produced vehicles in recent years. A HUD typically allows information to be presented to the driver within the normal line-of-sight. Usually, a HUD is designed in a way that the visual message is projected at a distance that is ahead of the vehicle. This means that the driver does not need to redirect focus. Because a display, in combination with a light source is used, different types of visual information could be presented on the HUD. However, when excessive information is presented on a HUD, it could become obstructive. Therefore, it is better to limit the information on the HUD only to information that is relevant at all times, like speed, ADAS or safety-critical interventions.

Two major types of HUDs could be distinguished; the ones that project directly on the windshield and the ones that project on a combiner glass. By projecting the information directly on the windshield, the driver always has access to information directly within the line of sight. To implement this technology, a specific type of windshield needs to be used (Continental, 2019). Figure 23 presents the details of such a system (Continental, 2019).This technology has been used by brands such as Toyota, BMW, Honda, Mercedes, Audi, Volvo and Jaguar (Toyota, 2018; Audi, 2019; Honda, 2019; Hyundai, 2019; Park and Park, 2019).

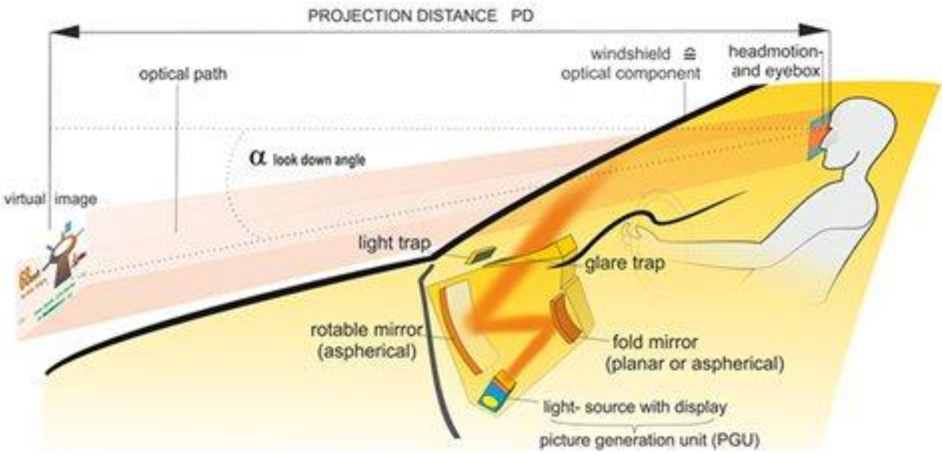

Figure 23: Head up display projected directly on windshield (Continental, 2019)

The combiner method uses a semi-transparent component, the combiner glass, on which the image is projected, as shown in Figure 24. This technology has a smaller footprint and is more cost-effective compared to direct windshield projection. Combiner-projection technology is used by brands like Hyundai, Citroën/Peugeot, Mazda, Renault, Ford (Ford, 2018; Citroën, 2019; Park and Park, 2019).

Figure 24: Combiner Head up Display (Continental, 2019)

The projection area for both the combiner method and the projection directly on the windshield is limited by the size of the display used for projection. Therefore, projection is only possible on a limited section of the complete field of view of the driver. At the moment, technology is being researched to transform the HUD in an augmented reality device by increasing the projection area to the entire windshield. For aftermarket installations, HUDs of comparable quality and specifications as the systems that are used by OEMs, are unavailable because they need to be integrated into the dashboard and use a lot of space. However, more compact systems that could be placed on top of the dashboard are available. New devices, however, like the Hudway cast (Hudway LLC, 2019) and Hudly Wireless (Hudly, 2019) use the cast function of smartphones to cast the complete phone screen, including custom made apps for HUDs.

3.2.1.3 Augmented Reality

Augmented reality is an expanded version of a traditional HUD display where the complete windshield is used as a projection area, as shown in Figure 25. This offers significant possibilities of enhancing reality with information displayed at the location where it would be most relevant. At the moment this system is not commercially available, but automotive manufacturers seem to agree that this technology offers considerable potential. Companies such as Continental (Continental, 2019) and Wayray (WayRay, 2018) are working together with motor vehicle companies to develop augmented reality systems. Meanwhile, Apple also submitted a patent for its own automotive augmented reality system (United States of America Patentnr. WO2017/053616, 2018). In January 2019, a first prototype vehicle was presented by Hyundai at CES 2019 (Hyundai, 2019).

Figure 25: Prototype of a Hyundai Genesis G80 with Augmented reality technology (Hyundai, 2019)

3.2.1.4 Centre console display

Originally, the centre console typically is a place where secondary driver controls such as climate control and the radio are located. In recent years, more cars are equipped with a centre display that is used as visualisation for these controls or even with a touch screen panel that replaces the controls completely. These displays offer the possibility to present detailed information to the driver. However, because these displays are far away from the normal line of sight, they should only be used to display secondary information such as fuel consumption or a map. For real-time interventions centre console displays should only be used to display more detailed information, in addition to a more intrusive warning presented elsewhere. For instance, when there are roadworks up ahead, an auditory warning could be triggered, accompanied by more detailed information on the centre display (distance to roadworks, length, and time loss). As a third-party, it is not possible to directly interface with these centre console displays. However, some vehicle types offer the functionality to pair with a smartphone through Android Auto (Android, 2019) or Apple CarPlay (Apple Inc., 2017). As a platform for third-party or aftermarket interventions, Android Auto or Apple CarPlay are not useful because these services are not available in all countries (Android, 2019; Apple, 2019) and only work with supported apps for navigation, communication and multimedia.

3.2.1.5 Side-view Mirror

The side-view mirror is used by almost all automotive OEMs for blind-spot warning. This makes perfect sense as the driver is expected to check the side-view mirror before starting a lane-changing maneuver. When a vehicle is detected in the blind-spot, a (mostly) amber symbol will be displayed (Jeong and Green, 2013). Because the side-view mirror is far away from the normal field of view, it should only be used to display non-critical warnings that relate to actions for which the side-view mirror is used.

3.2.2 Auditory

For auditory interventions, not much variation in technology has been found. All auditory interventions are generated by a speaker. A distinction can be made between the in-vehicle audio system and speakers that are part of a nomadic device. The advantage of using the in-vehicle auditory system to generate auditory interventions is the possibility to override other tasks performed by this system (radio, navigational instructions, etc.) that can otherwise complicate the reception or understanding of the auditory intervention. Because the in-vehicle audio system usually uses speakers in a surround configuration, the possibility to generate interventions at a more relevant position (left/right) exists. In general after-market systems cannot override the in-vehicle auditory system, unless the user chooses to use a nomadic device as source for the in-vehicle auditory system, for instance through a stereo jack cable or Bluetooth pairing.

3.2.3 Haptic

3.2.3.1 Steering wheel

In the automotive industry, haptic feedback (in form of vibration or resisting torque) through the steering wheel is mainly used as an intervention in lane departure warning systems. For instance, a lane departure warning system by Jaguar, as used in the Jaguar XE, gives the driver a visual alert combined with a gentle vibration of the steering wheel when the driver crosses the lane markings without using the indicator (Jaguar BeLux, 2018). Similar systems, such as the system developed by Bosch, with the option to provide haptic feedback through the steering wheel, are used in trucks and buses since a lane departure warning system became mandatory in the EU for commercial vehicles of +3.5 tons and busses of +5 tons (Robert Bosch GmbH, 2019).

Certain manufacturers also use steering wheel vibrations to capture drivers' attention or to maintain alertness. For instance, the Driver Attention Monitor System (DAMS) by Honda monitors driver alertness, if an inadequate level of attention is detected and the driver doesn't respond to visual warnings, steering wheel vibration will be used to further urge the driver to take action (American Honda Motor Co, 2018). From a technological point of view, a system for haptic steering wheel feedback needs an actuator on the steering column. For vehicles already equipped with electrical power steering, haptic steering wheel feedback can easily be integrated by the manufacturer through the power steering motor. For safety reasons, third party actuation of the power steering motor is not possible. Another option is to use a vibrator on the steering column. An example of such an aftermarket application is the Mobileye Vibration add-on which can be installed on the steering column to provide vibrations (Mobileye, 2019).

It can be concluded that haptic feedback through the steering wheel already features in various recent vehicles, mainly to provide interventions that are part of a lane departure warning system. This makes sense as interventions through the steering wheel should ideally relate to steering actions. As seen in almost all the current applications, haptic interventions should always be part of a multimodal system because a haptic intervention on its own can attract attention but gives very little information. For OEMs this technology can easily be implemented in vehicles already equipped with electrical power steering. Aftermarket installation of this technology is difficult, although systems such as the Mobileye Vibration Add-on do exist. In order for this technology to be effective, the driver needs to have at least 1 hand on the steering wheel.

3.2.3.2 Driver Seat

Haptic alerts can also be provided through the driver seat. The advantage of such a technology is that the driver is always maintaining contact with the seat (Fitch et al., 2011). This implies that the risk of the warning being unnoticed is lower, with the exception being when the intervention gets lost in vibrations caused by external factors such as high levels of ambient noise or extreme weather temperatures.

Haptic seat interventions are already used in cars. For example, Citroën uses haptic seat feedback, with actuators on both sides of the seat as part of the lane departure warning system in the DS5 (Citroën, 2019). A similar system is used by General Motors, where the driver receives haptic warnings through the seat for lane departure and collision avoidance (Weiss, 2012; Brzozowowski, 2015). Unless a vibrator would be installed underneath the seat, this technology requires actuators underneath the upholstering, within the cushioning of the driver seat. For this reason, haptic driver seat technology is only available as an OEM technology.

3.2.3.3 Pedals

At the International Motor Show 2015, in German known as the Internationale Automobil-Ausstellung Conference (IAA), Bosch presented its Active Gas Pedal. This technology features a pedal equipped with actuators that can provided pedal resistance as well as pedal vibrations (Robert Bosch GmbH, 2019). It was suggested that this technology could be used for numerous types of information such as ideal shifting point, exceedance of the speed limit, traffic alerts or collision warnings and increased resistance in conditions when fuel can be saved (Ackerman, 2016). However, as of today, this technology was not available as OEM equipment in vehicles. In general, this technology could be valuable to influence driver behaviour. Some studies also suggested that a haptic gas pedal could be useful in safety-critical situations in the context of forward-collision warnings (Lylykangas et al., 2016a). With an essential condition being that the driver has his foot on the pedal.

There are two approaches to the implementation of a haptic pedal. The first is by using a motor that acts on the pedal’s rotation. This motor can provide resistance as well as vibrations. This requires changes to the design of the pedals, so it needs to be implemented by the OEM. The second approach is by mounting a vibrating motor on the pedal. In theory, this can be installed as an aftermarket solution, but it would require the custom design of mounting brackets because there is a substantial variation in pedal shape.

3.2.3.4 Seatbelt

In Europe, wearing a seat belt has been compulsory in all vehicles since 2006 (European Comission, 2006). This means that in theory, the driver should be in contact with the seatbelt at all times while driving, making vibrations applied through the seatbelt a possible solution to provide interventions. Certain studies already suggested that the seatbelt could be used to provide safety-critical interventions in the context of a collision warning system (Mohebbi et al., 2009; Chun et al., 2012), blind spot warning (Chun et al., 2013) or drowsiness detection (Arimitsu et al., 2006).

In order to generate haptic seat belt interventions, actuators that move or vibrate the seatbelt are needed. The Belt-in-Seat (BIS) is a three-point harness with the shoulder belt attached to the seat itself, rather than to the vehicle structure. BIS type belts have been used by automakers in convertibles and pillarless hardtops. One method is by having a motor in the B- or C-Pillar that pulls the seatbelt. Just for better understanding, B-Pillar is the pillar on both sides just behind the driver's seat as well as C-Pillar is the third pillar generally behind the passenger's seat. Such actuators are already present in most cars in the form of pyrotechnic actuators that fire one time in the event of a crash. However, brands such as Mercedes and BMW are installing electric motors to achieve seat belt tensioning during a crash and automatic adjustment on start-up (Daimler AG, 2014). Another method is by using an actuator that pulls on the seatbelt buckle. Such active buckle systems are at present used by brands such as Mercedes (Daimler, 2012). Both of these methods need to be implemented by the OEM. A third method, which can be used for after-market installations is by mounting a vibration motor on the belt itself. An example of this method is the seat belt vibration alert module, which is commercially available as an add-on for the ADAS+ system by Brandmotion (Brandmotion, 2015). Another example of haptic seat belt interventions can be found in the motorised seat belt kit by Schroth (Schroth Safety Products LLC, 2018). This is a commercially available system, designed for off-highway vehicles. This system provides a haptic warning when a risk of roll-over is detected.

3.2.4 Nomadic Devices: Auditory/Visual/Haptic

A nomadic device is a device for information including entertainment, and/or communication that can be used outside of the vehicle and inside the vehicle by the driver while driving. It is not supplied or installed by the vehicle manufacturer (eSafety Forum, 2005). There are many different types of nomadic devices that can be used to generate visual, auditory and haptic real-time interventions, ranging from all-round devices such as smartphones to devices that are specifically designed for real-time interventions such as the Mobileye EyeWatch.

The most frequently used nomadic device is the smartphone, which is used by many drivers as navigation through apps like Google Maps and Waze, these apps do in fact already provide some real-time interventions to the driver through the smartphone. For instance, the app Waze provides interventions (visual and auditory) for exceeding the speed limit or obstacles reported by other users (EENA, 2018). While being a useful device to provide information such as navigation to the driver, a smartphone is very limited with regards to safety-related real-time interventions. The use of the system always needs to be initialized by the driver by mounting the device and starting an application. With devices capable of providing entertainment, communication and other multimedia, there is also the risk that the driver will use this function during driving, creating a distraction from the driving task.

Other devices, that are less portable and meant to be permanently installed in the vehicle, might be a better solution for a system that aims to improve safety. An example of such a device is the EyeWatch by Mobileye, depicted in Figure 26. This device is used by MobilEye to present safety-related real-time interventions to the driver such as forward collision warning and lane crossing alerts. Interventions can be both visual and/or auditory.

Figure 26: Mobileye EyeWatch, an example of a non-portable nomadic device. (Mobileye Vision Technologies Ltd., 2014)

For visual nomadic devices, positioning of the device is particularly important. To avoid distracting or long gazing times, visual interventions should be given within the drivers' field of view, preferably as close as possible to the viewpoint on the road. On the other hand, if installed too much within the field of view, there is the risk that the device might become obstructive and block the drivers' view on the road (Janitzek et al., 2010). Another possible disadvantage of nomadic devices is that there is a lack of communication with other systems within the vehicle and that there is no option to override these other systems. For instance, a nomadic device triggers an auditory warning, but at the same time, the driver is listening to the radio at a high volume. This might cause the auditory warning to go unnoticed by the driver. If there would be communication with the auditory system, the volume of the intervention could be increased, or the volume of the auditory system could be lowered.

Similarly, for a visual intervention, without communication with other vehicle systems, the nomadic device has no way of knowing what information is already being displayed to the driver. This might lead to an overload of information or even confusion if the information is contrary to each other. For instance, the Mobileye EyeWatch gives a visual warning when the time headway distance to the vehicle ahead is too low, but some vehicles might already be equipped with a headway monitoring system installed by the OEM. These systems are operating completely separate from each other and will very likely display warnings at different thresholds levels.

For nomadic devices, it can be concluded that mobile all-round devices such as smartphones can be useful to provide non-safety-related information only to the driver because they have to be set-up at the start of every trip. Furthermore, smartphones provide the opportunity to access multimedia, which causes distraction from the driving task. Devices that are more permanent and that are specifically designed to provide real-time interventions are a better choice for safety-related interventions. However, without communication with other in-vehicle systems, these devices cannot be adapted to the situation and might even provide information that is contrary to the information given by other in-vehicle systems.

3.2.5 Discussion & Recommendations for i-DREAMS

This overview of intervention technologies will be used as a basis for selection of suitable intervention technologies for the i-DREAMS project. For the on-road testing, feasibility is a critical consideration. The chosen technologies should be capable of providing custom designed interventions, based on sensor measurements and the STZ algorithm. This means that interfacing with an i-DREAMS processing unit is a requirement. This constraint means that technologies that were controlled by the OEM, such as the dashboard or centre display, cannot be used within i-DREAMS during the on-road experiment. Another aspect that needs to be considered is ease of installation. Given the significant number of vehicles that will be equipped with i-DREAMS technology, an efficient installation process is essential. This can only be achieved when the installation process is standardised as much as possible, meaning that haptic devices such as driver seat vibration, pedal vibration and steering wheel vibration are not ideal because they require custom fabrication of parts and/or require (dis)assembly of larger vehicle parts. Based on these constraints, the most convenient solution for the on-road experiments would be the use of a carefully chosen nomadic device that is able to give visual and auditory interventions. Smartphones, Mobileye and Eyewatch are some of the most common technologies that are utilized in the automotive industry.

For the simulator experiments, there are fewer constraints. Sensor data can easily be captured from the simulator. The limited number of simulators eliminates the requirement for installation standardisation, custom design and fabrication of parts and interfaces is a possibility. Technologies that are difficult for the on-road experiment, such as tactile interventions or dashboard display, can be tested in the simulator. Table 4 depicts an overview of these available real-time intervention technologies.

Table 4: Assessment of real-time intervention technologies

Modality	Technology	Assesment	Assessment
V	Dashboard display	● (green)	versatile, can display detailed information, available in all cars
V	HUD	● (green)	versatile, within line of sight
V	Augmented Reality	● (red)	risk of distraction, not commercially available
V	Centre Console Display	● (red)	far from normal line of sight
A	In-vehicle auditory system	● (green)	overrides music, provides navigation, can be positioned in multiple locations (left/right)
H	Steering wheel	● (green)	intuitive to steering actions (lane keeping)
H	Driver Seat	● (red)	limited information, no available solutions
H	Pedals	● (orange)	intuitive with regards to feet actions, contact is required, limited information and applications
H	Seatbelt	● (green)	aintains contact with driver
V & A & H	Nomadic devices	● (green)	many different devices are available, many options for interventions, commercially available in all vehicles
Modality V: Visual, A: Auditory, H: Haptic **Assessment**● (green): Good, ● (orange): Neutral , ● (red) Bad.			

3.3 Mode-specific literature review

This section provides the results of a transportation mode-specific literature review which aimed to investigate the utilization of real-time interventions in cars, trucks, buses and trains. The targeted risk factors, the technical equipment, the corresponding intrusiveness and reliability of the devices as well as an overall assessment and recommendations for the i-DREAMS systems are described. Literature was searched within popular scientific databases such as Scopus, ScienceDirect and Google Scholar. An example of key words used per factor analysed, as well as the number of screened and included papers is given on Table 5.

Table 5: Key words, screened and included papers per factor analysed

Mode	Key words	Screened papers	Included papers
Cars	"real-time interventions" OR "in-vehicle interventions" OR "real-time feedback" OR "real-time technology" OR "feedback" AND "car drivers" AND "cars"	70	22
Trucks	"real-time interventions" OR "in-vehicle interventions" OR "in-vehicle feedback" OR "feedback technology" OR "feedback" AND "truck drivers" AND "trucks"	47	9
Buses	“real-time interventions” OR “real-time feedback” OR “feedback” OR “interventions” OR “on-job training” OR “telematics” OR “feedback technology” AND “bus” AND “coach” AND “bus driver” AND “coach driver”	112	36
Trains	"real-time interventions" OR "in-vehicle interventions" OR "real-time feedback" OR "real-time technology" OR "feedback" AND "trains" AND "railway"	196	1

3.3.1 Cars

In-vehicle technologies include dedicated information system tools to understand driving conditions, environment, and behavior. They are able to provide real-time interventions to car drivers in order to improve their driving behavior and promote road safety. Based on the literature review, visual auditory and haptic warnings or combinations of both were found to enhance driving safety and were the most popular among the studies investigated.

In-vehicle signal systems with an on-board display such as the multi-modal detection system, SASPENCE, as well as in-vehicle auditory systems such as CarChip Fleet Pro and Sound Blaster X-Fi system were the most efficient real-time driver distraction detectors. These widespread technologies were highly acceptable as they were easy to install and accessible to vehicle data. Furthermore, multisensory wearable modules and in-vehicle OAMS were found to have a robust and statistically significant effect of real-time feedback on both drowsiness and driving performance ratings. In addition, safe and eco-driving applications were a cost effective way to modify drivers’ behavior positively providing real-time feedback during driving. For instance, DriveGain and Drivewise were found to assess driving risk more accurately. Dutch navigation system and Zephyr BioModule Device were less effective and acceptable by the drivers as these technologies required attention resources, which could distract from driving. Finally, haptic technology was not utilized on a large scale but nonetheless vehicle's warning systems were reliable, relatively simple and inexpensive. An overview of the results of the review on real-time intervention technologies for cars is depicted in Table 6.

Table 6: Overview of studies utilizing real-time interventions in cars and their assessment

Year	Authors	Risk factors	Indicators	Technical equipment	Type of feedback	Assesment	Acceptance/Effectiveness
2019	Braun et al.	emotions	driving performance, eye glances, driver workload, emotional state, HR, anger, sadness	GSR , camera, LED strip, CID, electrodes, Tobii X2-60 eye-tracking device /DS	V & A	🟡	no indication of increased visual activity for any strategy
2019	Raviteja and Shanmughasundaram	colission	lane changes	monoscopic camera, ultrasonic sensor, LIDAR, RADAR, lane detection and tracking, LDWS, BDWS, Anisotropic Magneto-Resistive sensor, buzzer	V	🟡	NA
2019	Arumugam and Bhargavi	fatigue, drowsiness, distraction	SP, driving performance, acceleration, braking, cornering	drivewise app, GPS, / OBD, SP	V	🟢	assess the driving risk more accurately
2019	Wong et al.	distraction	RT	/SP, DS	A	🟢	quicker response to assertive voice commands despite how immersive the secondary task was
2018	Paredes et al.	stress, distraction, driving performance	ECG, HR, HRV, EDA, lane-keeping	linear resonant actuators, speakers, Zephyr BioModule Device 3.0 /DS	A & H	🟢	neither the haptic nor voice modality impaired safety and driving performance
2018	Hasenjager and Wersing	drivers' preferences, driving styles, skills and patterns	lane change, lane keeping, FCW	ADAS system	V	🟡	NA
2018	Dehzangi et al.	distraction	ECG,GSR, CAN- Bus signal	multi-modal detection system, accelerometer, gyroscope /NDE,OBD	V & A	🟢	capability for efficient online driver distraction detection
2018	Balters et al.	drowsiness, physiological performance, alertness, focus	BRPM, HR, BI, speeding	cameras, haptic vibrotactile seat, Zephyr BioModule Device 3.0, BioModule Bluetooth /DS	H	🔴	fast breathing required attention resources, which could distract from driving
2018	Van der Heiden et al.	distraction, driving performance, lane change	RT, lane change distance, subjective workload	Dutch navigation system, Logitech G27 racing wheel, 29" monitor /DS	V & A	🔴	distraction by auditory task
2017	Li et al.	driving performance	SP, acceleration rates, emission rates braking distance to the STOP sign.	RFID based DSAS, high frequency active RFID tags 2.4 GHz tag with adjustable transmit power, RFID reader, in-vehicle signal system with an on-board display or an in-vehicle auditory system, GPS /OBD,FS	V & A	🟢	worthy to place DSAS in their vehicles

2016	Rios-Torres and Malikopoulos	driving safety and efficiency	acceleration, braking smoothly, keeping a steady speed, shift up early	CWS, radar, laser, camera, sensors, GPS /OBD	V & A	●	drivers automate difficult or repetitive tasks
2015	Aidman et al.	drowsiness, sleepiness,	lane-keeping, headway, responsiveness	monochrome LCD screen attached to the dashboard, Optalert glasses, in-vehicle OAMS /NDE	V & A	●	robust and statistically significant effect of OAMS feedback on both drowsiness and driving performance ratings
2015	Zhao et al.	eco-driving	SP, quick accelerate, rapid decelerate, shift gear	OBD2 device, eco-driving support system, WiFi /DS	A	●	cost-effective and easily to apply without complicated installation, friendly to drivers
2013	Zhao & Wu	driving performance, speeding	SP (frequency, duration, magnitude), RT, lead vehicle braking response (TTC), subjective measures	STISIM simulator, Sound Blaster X-Fi system, 27-inch LCD, 12.1 inch ELO screen /DS	V & A	●	effectiveness and acceptance of ISPS and ISA
2012	Tulusan et al.	eco-driving performance	SP, acceleration, braking, distance, duration, start/end location, overall time	DriveGain Ltd, GPS sensor, eco-driving app /SP	V & A	●	cost effective way to modify drivers' behavior positively providing real-time feedback during driving
2012	Roberts et al.	distraction	eye movements, head-tracking, seat sensor data	real-time mitigation system, LED lights /DS	V & A	●	the real-time system was more obtrusive and less easy to use
2012	Lee & Chung	fatigue, drowsiness	HR, BP, ECG, PPG, TP, SP, PERCLOS	accelerometer, front camera of the device, Bluetooth, Fuzzy Bayesian network, temperature sensor /DS,SP	A	●	a higher complexity yielding might slow down the overall processing of the smartphone device
2011	Adell et al.	driving performance, speeding, lane change	SP, RT, lane keeping, lane change, driver workload	SASPENCE ADAS system /FS	V	●	acceptance of intervening and advisory system
2010	Lu et al.	driving performance	acceleration, SP,	MOST bus system, CAN bus, acceleration sensor	V & A	●	NA
2008	Katsis et al.	emotions, stress, disappointment, euphoria	EMG, ECG, EDA, RR	multisensorial wearable module, EMG sensors, three-lead ECG sensor, hall-effect respiration sensor, EDA sensor, centralized computing module, system's interface /DS	V	●	high performance
2007	Al-Taee et al.	speeding performance	location, fuel-level, engine temperature, SP, latitude/longitude position	OBSD, GUI, GPRS, remote server, GSM network, GPS interpreter, OBD-II Interface, TCP transmission module	V & A	●	highly reliable and accurate supervision from inside the vehicle
2007	Staff et al.	driving performance	SP, harsh braking, acceleration, start/end time	CarChip Fleet Pro, USB port /OBD	A	●	easy to install and accessible to vehicle data
2000	Yanko et al.	driving performance	SP, acceleration	accelerator pedal, vehicle's warning system	H	●	reliable, relatively simple, inexpensive, easily installed on new vehicles

where OBD: On-Board Diagnostics, DS: Driving Simulator, P: Patent, SP: Smart Phones, NDE: Naturalistic Driving Experiment, FS: Field Study, NA: Not Applicable, V: Visual, A: Auditory, H: Haptic,
Assessment in terms of Acceptance/Effectivenss ●: High, ●: Medium, ●: Low.

3.3.2 Trucks

Several commercial systems and technologies, providing real-time interventions to truck drivers, were investigated and the results indicated that there was little evidence on truck-specific applications. Most of the applications were focused on collision avoidance, as well as the avoidance of fatigue, distraction or inattention.

With regards to truck drivers, they were willing to accept technology and agree that technology, if designed and introduced properly, can provide useful feedback to improve safe driving and efficiency as well (Roetting et al., 2003). Technologies that were utilized to detect and monitor truck driving behaviour in real-time were non-intrusive, mainly through a web-based safety platform. DMS such as FleetCam, SmartDrive, Bendix Wingman Fusion system and Nauto Prevent were found to improve driver reliability and safety, providing satisfaction to the truck operator. The IVMS vendor had low-cost in comparison to other safety technologies and the effectiveness of feedback from IVMS reduced risky driving behaviors. In contrast, Driveri vision-based platform was not utilized by non-professional operators and personal car users, due to the device's expensive cost. An overview of the results of the review on real-time intervention technologies for trucks is depicted in Table 7.

Table 7: Overview of studies utilizing real-time interventions in trucks and their assessment

Year	Authors	Risk factors	Indicators	Technical equipment	Type of feedback	Assesment	Acceptance/Effectiveness
2019	Ahmed et al.	colission, weather conditions	speed, spot weather, road surface condition	CV: technology, FCW, DNs, TIMs, TTC sensor /DS	A & V	🟢	readily implementable for state-wide training of commercial truck drivers
2019	FleetCam	driving performance	eye movements, time, speed, direction	FleetCam DMS, camera, sensors, artificial intelligence /OBD	A & V	🟢	security and transparency of truck fleets, driver satisfaction, reliability, safety
2018	Akerkar	distraction, collision, high-risk events	speeding, harsh acceleration, rapid deceleration, lane departures, swerving, driver's head, eyes, torso	Nauto Prevent DMS, dual-facing camera, computer vision, proprietary algorithms /OBD	V	🟢	important proactive solution, fewer distractions and collisions
2018	Aaron Huff	inattention, distraction, fatigue, drowsy driving behaviour	eye movements, head positions, speeding, harsh braking, drivers' gaze, following distance	SmartDrive SR4 platform, camera, sensors, software algorithms /OBD	V	🟢	significantly enhanced functionality to support computer vision and ADAS capabilities
2018	Aaron Huff	distraction, collision	speed limit, braking, distance, lane position	Bendix Wingman Fusion system, radar, video, brake system, camera, Collision Mitigation Technology, LDWS /OBD	A & V	🟢	improve driver reliability and safety
2017	Bell et al.	distraction, inattentive driving, fatigue, aggressiveness,	harsh vehicle maneuvers, speeding, vehicle control, stopping, texting on hand-held phone, hands off the wheel, driving the wrong way	small box-like device IVMS vendor, forward-facing exterior camera view, driver-facing interior camera /NDE	V	🟢	low-cost in comparison to other safety technologies
2017	Stephen et al.	distraction, fatigue, traffic light violations, unsafe tailgating	harsh braking/accelerating, following distance, speeding, rolling stops and yawning	Netradyne, Driveri vision-based platform, cameras /OBD	V	🔴	expensive cost of this device, not for non-professional operators and personal car users
2017	Fitzharris et al.	distraction, fatigue, drowsiness	eyelid position, fatigue incidence rates and operational timing of occurrence, distance traveled	DMS, in-vehicle camera, VGA 60Hz global shutter image sensor, 850-nm infrared lights /OBD	A & H	🟢	fewer fatigue events were a reflection of the device
2017	eDriving	distraction	acceleration, braking, speeding, mobile phone usage	Mentor app, sensors /SP	A	🟡	NA

where OBD: On-Board Diagnostics, DS: Driving Simulator, SP: Smart Phones, NDE: Naturalistic Driving Experiment, NA: Not Applicable, V: Visual, A: Auditory, H: Haptic,
Assessment in terms of Acceptance/Effectivenss 🟢: High, 🟡: Medium, 🔴: Low.

3.3.3 Buses

Real-time safety interventions for buses attract a lot of attention nowadays due to the importance of safety, vehicle maintenance and eco-driving for bus operators. The majority of bus interventions exploit CAN bus, GPS and camera data in order to assist drivers in heavy duty navigation, blindspot monitoring as well as the avoidance of harsh events. Most of the state-of-the-art technologies in real-time bus interventions provide visual and auditory alerts to drivers. New technologies utilizing only cameras have also emerged with solution in terms of pedestrian and vulnerable road user's detection but in general they are depending on the hardware that is used for integration with the bus systems.

Among many technologies, ZF Openmatics, WebFleet and MixFleet were indicated as the best option for ensuring safety, operational efficiency, compliance and consulting. Although eco-driving is becoming more and more essential in today's transportation environement, only a few applications take it into account, with GreenRoad and Trimble providing the best performance. Trimble has been indicated as the most comprehensive intervention approach as it combines real-time and historic information to inform and consult drivers on fuel efficiency, emission, vehicle faults as well as safety distances and speeds. Applications developed by fleet manufacturers (e.g. Daimler, Volvo, MAN) are less transferable to other fleets. Finally, little information has been found on the acceptance of safety interventions from bus drivers, but advantages for fleet operators are visible in terms of continuous vehicle surveillance and driver compliance to traffic rules.

An overview of the results of the review on real-time intervention technologies for buses is depicted in Table 8.

Table 8: Overview of studies utilizing real-time interventions in buses and their assessment

Solution/Product	Type of data	Indicators	Assesment	Type of feedback
ZF OPENMATICS	Vehicle CAN bus data, GPS, 9 DOF IMU, 3D compass, 3D accelerometer, 3D gyroscope, Altimeter	engine/vehicle SP, idling time, harsh braking, harsh acceleration, extensible by 3rd party hardware using zf openmatics skd and api	🟢	V & A
WEBFLEET OptiDrive 360/ Bridgestone (formerly TomTom)	vehicle can bus data, GPS, 6 dof imu, 3d accelerometer, 3d gyroscope, digital mapping, camera (optional)	heavy duty navigation maps, engine speed, vehicle speed, idling time, harsh braking, harsh acceleration, real-time coaching with predictive driving tips, 2-way communication with fleet manager, extensible by 3rd party hardware using api or app centre (e.g. alcohol monitoring)	🟢	V & A
FLEATBOARD/ Daimler	vehicle can bus data, GPS, 3d accelerometer, 3d gyroscope, digital mapping	heavy duty navigation maps, working time, eco driving coaching tips, 2-way communication with fleet manager, extensible by 3rd party hardware using api and integration with erp via web service	🟡	V & A (limited to some Daimler models)
OMNIPlus ON/ Daimler	vehicle can bus data, GPS ,3d accelerometer, 3d gyroscope, digital mapping	heavy duty navigation maps, working time, eco driving coaching tips, 2-way communication with fleet manager, extensible by 3rd party hardware using api and integration with erp via web service	🔴	V (not focused on performance real-time feedback)
MixTelematics Fleet Manager	vehicle can bus data, GPS, 3d accelerometer, 3d gyroscope, video camera	heavy duty navigation maps, engine speed, vehicle speed, idling time, harsh braking, harsh acceleration	🟢	V & A
Volvo Bus Telematics and i-Coaching	vehicle can bus data, GPS, 3d accelerometer, 3d gyroscope, v	engine speed, vehicle speed, idling time, harsh braking, harsh acceleration, harsh cornering, lateral body roll	🟢	V & A
IVECO BUS Fleet Management (FleetVisor)	vehicle can bus data, GPS, 3d accelerometer, 3d gyroscope, video camera	acceleration,braking, harsh cornering, eversing video monitoring, blind spot monitoring, surround omniview	🟢	V & A
MAN Digital Services, Fleet Management and RIO	vehicle can bus data, GPS, 3d accelerometer, 3d gyroscope,	2-way communication with fleet manager, contextual speeding, harsh braking, acceleration and cornering, rollover alert	🟢	V & A
GreenRoad Bus & Coach telematics	vehicle can bus data, GPS, 3d accelerometer, 3d gyroscope, video camera	Manoeuvre, acceleration, braking, harsh cornering, lane handling, speeding, 360-degree video	🟢	V & A
Trimble Transport & Logistic Telematics, Performance Portal and Driving Style Assistant	vehicle fms and can bus data, GPS, 3d accelerometer, 3d gyroscope, video camera	vehicle fms data, driving style, including fuel efficiency, 2-way communication with fleet manager, contextual speeding, harsh braking, acceleration and cornering, excessive engine speed, gearbox management video feed, blind spot monitoring alerts	🟢	V & A
Transics Telematics and Fleet Management Systems/ (WABCO)	vehicle fms and can bus data, GPS	in vehicle real time feedback, vehicle fms data, driving style, including: fuel efficiency, harsh braking and acceleration, excessive engine speed gearbox management, 2-way communication with fleet manager	🟢	V & A (allows custom tailored integration)

VDO TIS-Web Fleet Management and DriverLinc/(Siemens)	vehicle fms and can bus data, GPS	driving style, fuel efficiency,harsh braking and acceleration, excessive engine speed, gearbox management, 2-way communication with fleet manager	●	V & A
Frotcom FMS Driver Feedback Light Bar	vehicle can bus data, GPS, 3d accelerometer,	vehicle speed, engine speed, usage of cruise control, idle time, acceleration, braking	●	V & A
Lightfoot Real Time Feedback/ Ashwoods Automotive	vehicle fms and can bus data, GPS, 3d accelerometer	speeding (vehicle speed), overreving (engine speed), idling time, harsh braking, harsh acceleration	●	V & A
VERICITY MixedFleet	vehicle fms and can bus data, GPS, 3d accelerometer	speeding (vehicle speed), overreving (engine speed), idling time, harsh braking, acceleration and cornering	●	Via 3rd-party
ACTIA Telematics, Fleet Management and DriverAid	vehicle fms and can bus data, GPS	speeding (vehicle speed), overreving (engine speed), idling time, harsh braking, acceleration and lateral acceleration, fuel economy	●	V & A
Verilocation Telematics Products Suite	vehicle can bus data, GPS, 3d accelerometer, video camera	in vehicle real time feedback, vehicle can bus data, 2-way communication with fleet manager, driving style, including: fuel efficiency, speeding, harsh braking, acceleration and cornering, video feed, blind spot monitoring alerts, breathalyser for alcohol monitoring with interlock system	●	V & A
Zonar Coach	vehicle can bus data, GPS, 3d accelerometer, video camera	posted/context speed limits, tailgating/fcw, fail to comply with stop signs, lane drift/ldw, context based harsh braking, cornering and acceleration rate	●	V & A
Samsara Driver Safety and Coaching Platform	vehicle can bus data,GPS, video camera	harsh braking and acceleration, harsh cornering, safety critical events	●	V & A (using Driver App)
Fleetistics	vehicle can bus data	harsh braking and acceleration	●	Ac (via GEOTAB GO)
CardioWheel/ CardioID	vehicle can bus data, GPS, steering wheel (angle and angular speed), non-intrusive ecg, (hearth rate and hr variability)	fatigue and drowsiness, driver distraction, aggressive driving (optional)	●	A & H
Driveri/ Netradryne	3d accelerometer, 3d gyroscope, video camera, GPS	g-force events, hard braking and acceleration, traffic signal recognition and violations, stop sign and red light compliance, contextual speeding violations, following distance, seatbelt compliance, u-turn manoeuvres, driver drowsiness	●	V & A
SmartWitness	3d accelerometer, video camera	blind spot monitoring 360-degree surround view distraction and drowsiness	●	V & A
iDrive AI Camera and IRIS Fleet Management Platform	GPS, 3d accelerometer, 3d gyroscope, video camera	g-force events, harsh braking and acceleration, following distance, seatbelt compliance, speeding violations, distraction and drowsiness	●	V & A

Guardian (aftermarket add-on for GEOTAB)/ Seeing Machines	camera based eye and face tracking	driver fatigue and distraction	● (green)	A & H
E-Horizon Road Weather Hazard Alert Service (add-on for GEOTAB)	weather-related service data and road hazards	hydroplaning risk (flooding/precipitation), low visibility risk (fog), icing risk (black ice/frozen rain), wind and gust risk, hail and lightning risk	● (green)	V & A
Safe Drive Systems advanced radar collision prevention	radar, camera, GPS	pedestrian warning, forward collision warning, headway/safe-distance monitoring, involuntary lane departure warning, speed limit	● (green)	V & A
Brodmann17 Aftermarket ADAS Software Suite	Camera	pedestrian warning, forward collision warning, headway/safe-distance monitoring, involuntary lane departure warning, distance measurement, object classification, time-to-collision	● (red)	Dependant of integration hardware
MobilEye 6, 8 Connect and Shield+	Camera	pedestrian warning, vulnerable road user detection, forward collision warning, headway/safe-distance monitoring, involuntary lane departure warning, time-to-collision	● (green)	V & A (option)
MiniEye ADAS Driving Monitoring Cloud Platform	Camera	pedestrian warning, vulnerable road user detection, forward collision warning, headway/safe-distance monitoring, involuntary lane departure warning, blind spot detection driver monitoring system	● (yellow)	Dependant of integration hardware
IntelliVision AI and Video analytics ADAS product suite	Camera	forward collision warning, time-to-collision (ttc), headway distance, lane departure warning, pedestrian detection, traffic road sign detection and recognition, blind spot vehicle detection and smart mirror (under development)	● (yellow)	Dependant of integration hardware
CUB ELECPARTS ADAS	24 and 77 ghz mm wave radar	blind spot detection, rear cross traffic alert, lane departure warning, forward collision warning, parking assist	● (yellow)	Dependant of integration hardware
WABCO's aftermarket ADAS	camera and 77 ghz mm wave radar	blind spot monitoring and vehicle detection, lane departure warning, forward collision warning	● (yellow)	Acoustic and/or Dependant of integration hardware
Aftermarket TPMS, Goodyear, Continental, Michelin, WABCO, ZF, Bendix, Pirelli, CUBS, white-label solutions	6 or 9 dof imu, 3d accelerometer, 3d gyroscope, pressure, temperature	pressure, temperature, tire rolling speed	● (green)	V & A
Aftermarket ADAS, With label and alternative Manufacturers (Smartcomm, Road iQ, Howen, Stonkam, DesignCore etc.),	camera, radar	driver monitoring system (drowsiness, distraction) blind spot vehicle detection, lane departure warning, forward collision warning, 360-degree surround video, camera mirror	● (yellow)	V & A Dependant of integration hardware

3.3.4 Trains

Rail signalling basic safety system controls the movement of trains. Traditionally, drivers react to line-side or colour signals to control train's speed in line with operation. However, drivers may fail to respond to a signal's indication, leading to several accidents. In response to this, various driver warning devices or signal command enforcement and auxiliary safety systems have been devised.

Any auxiliary safety system required installation of some degree of train borne equipment. It was revealed that Automatic Warning System (AWS) and Train Protection and Warning System (TPWS) were the two safety systems fitted in the majority of trains. Similar warning systems such as Automatic Train Protection (ATP) and Train Protection System (TPS) should be designed to alert drivers on excessive speeds, providing auditory and visual warnings or signals and apply emergency braking if needed.

3.4 Summary

3.4.1 Intermodal considerations for the i-DREAMS platform

The results of the literature review as well as the technology investigation indicated that providing real-time feedback to drivers, through in-vehicle intervention systems and strategies, could efficiently help them monitor their driving behaviour and lead to improved driving performance as well as road safety.

Auditory-visual sensors or eye-tracking might have lower initial hurdles regarding acceptance in cars and trucks, while visual information was the cornerstone of warning systems in real-time for trains. With the exception of trains, in-vehicle devices with small size, monitors, sound alerts, and smartphones could be easily modified and transferred in order to provide drivers with feedback in real-time. Nevertheless, what is currently missing from technologies and research, is interventions targeting driver capacity aspects that combine driving behavior and mental state of the operator.

With regards to cars, it was revealed that DSAS, CarChip Fleet Pro and SASPENCE advisory platform were the most reliable safety systems that provided real-time feedback as they were easy to install and accessible to all vehicle data. Multisensory wearable modules using EMG, ECG and EDA sensors as well as optalert glasses were highly acceptable from the drivers with regards to drowsiness and driving performarnce, however they require obtrusive installations. Smartphone eco-driving applications, such as Drivewise app and DriveGain were a cost effective solution that assessed the driving risk more accurately and provided real-time interventions while driving.

For truckers, an in-vehicle camera, such as FleetCam, Nauto Prevent and SmartDrive SR4 platform was found to work better. These DMS were found to be an important proactive solution with fewer distractions and collisions for professional operators.

State-of-the-art technologies such as ZF Openmatics, WebFleet and MixFleet were indicated as the best option for buses. Trimble was found to be the most comprehensive and modular telematics solution in the market regarding driver safety and fleet management. Lastly, GreenRoad was an eco-driving application which offered a best performance. Applications developed by fleet manufacturers, such as Daimler, Volvo, MAN were less transferable to other fleets.

Finally, ATP and TPWS were the best on-train monitoring recorders with emergency brakes application regardless of any action or inaction by the driver.

Table 9 summarizes the best technologies to measure targeted factors in real-time with regards to all transport modes considered in the i-DREAMS project. A detailed literature review of real-time interventions is given in Appendix D.

Table 9: Overview of target factors, metrics and data collection tools with regards to real-time interventions for all transport modes of i-DREAMS project

	Targeted at	Metrics	Car	Bus	Truck	Train
Operator behaviour	fatigue, drowsiness, distraction	SP, acceleration, braking, cornering	Drivewise app, GPS / OBD, SP			
	driving performance	SP, acceleration rates, emission rates braking distance to the STOP sign	RFID based DSAS, high frequency active RFID tags 2.4 GHz tag with adjustable transmit power, RFID reader, GPS /OBD,FS			
	drowsiness, sleepiness	lane-keeping, headway, responsiveness	in-vehicle OAMS, monochrome LCD screen attached to the dashboard, Optalert glasses /NDE			
	eco-driving	SP, quick accelerate, rapid decelerate, shift gear	eco-driving support system, OBD2 device, WiFi /DS			
	eco-driving performance	SP, acceleration, braking, distance, duration, start/end location, time	DriveGain Ltd, GPS sensor, eco-driving app /SP			
	driving performance, speeding, lane change	SP, RT, lane keeping, lane change, driver workload	SASPENCE ADAS system /FS			
	emotions, stress, disappointment, euphoria	EMG, ECG, EDA, RR	multisensorial wearable module, EMG sensors, three-lead ECG sensor, hall-effect respiration sensor, EDA sensor, centralized computing module, system's interface /DS			
	driving performance	SP, harsh braking, acceleration, start/end time	CarChip Fleet Pro, USB port /OBD			
	driving performance	SP, position	vehicle's warning system, accelerator pedal			
	driving performance	engine/vehicle SP, idling time, harsh braking, harsh acceleration, extensible by 3rd party hardware using zf openmatics skd and api		ZF OPENMATICS/ Vehicle CAN bus data, GPS, 9 DOF IMU, 3D compass, 3D accelerometer, 3D gyroscope, Altimeter		
	driving performance	heavy duty navigation maps, engine speed, vehicle speed, idling time, harsh braking, harsh acceleration, real-time coaching with predictive driving tips, 2-way communication with fleet manager, extensible by 3rd party		WEBFLEET OptiDrive 360/ Bridgestone formerly TomTom, vehicle can bus data, GPS, 6 dof imu, 3d accelerometer, 3d gyroscope, digital		

[redacted]		hardware using api or app centre (e.g. alcohol monitoring)		mapping, camera (optional)		
	driving performance	heavy duty navigation maps, engine speed, vehicle speed, idling time, harsh braking, harsh acceleration		MixTelematics Fleet Manager, vehicle can bus data, GPS, 3d accelerometer, 3d gyroscope, video camera		
	driving performance	manoeuvre, acceleration, braking, harsh cornering, lane handling, speeding, 360-degree video		GreenRoad Bus & Coach telematics, vehicle can bus data, GPS, 3d accelerometer, 3d gyroscope, video camera		
	driving performance	vehicle fms data, driving style, including fuel efficiency, 2-way communication with fleet manager, contextual speeding, harsh braking, acceleration and cornering, excessive engine speed, gearbox management video feed, blind spot monitoring alerts		Trimble Transport & Logistic Telematics, Performance Portal and Driving Style Assistant, vehicle fms and can bus data, GPS, 3d accelerometer, 3d gyroscope, video camera		
	driving performance	eye movements, time, speed, direction			FleetCam DMS, camera, sensors, artificial intelligence /OBD	
	distraction, collision, high-risk events	speeding, harsh acceleration, rapid deceleration, lane departures, swerving, driver's head, eyes, torso			Nauto Prevent DMS, dual-facing camera, computer vision, proprietary algorithms /OBD	
	inattention, distraction, fatigue, drowsy driving behaviour	eye movements, head positions, speeding, harsh braking, drivers' gaze, following distance			SmartDrive SR4 platform, camera, sensors, software algorithms /OBD	
	distraction, inattentive driving, fatigue, aggressiveness,	harsh vehicle maneuvers, speeding, vehicle control, stopping, texting on hand-held phone, hands off the wheel			small box-like device IVMS vendor, forward-facing exterior camera view, driver-facing interior camera /NDE	

	distraction, fatigue, drowsiness	eyelid position, fatigue incidence rates/operational timing of occurrence, distance traveled			DMS, in-vehicle camera, VGA 60Hz global shutter image sensor, 850-nm infrared lights /OBD	
	longitudinal movement	SP				ATP/OTMR
	longitudinal movement	SP, braking				TPWS/OTMR

3.4.2 Considerations of differences between professional and non-professional drivers

According to the studies investigated, real-time interventions for both personal and professional drivers were most frequently given through virtual graphical alerts, auditory alarm notifications or haptic signals. It was found that non-professional drivers used eye-tracking systems to record their driving performance. There might be difficulties using eye-tracking systems, such as optalert glasses or eye-tracking devices, due to GDPR permissions and acceptance by operators and drivers. In-vehicle monitor devices that were used in cars and provided real-time interventions through audible or haptic technology could also face difficulties in applications to truck and bus drivers as the latter might be more easily distracted from this kind of feedback due to long working hours. Furthermore, difficulties might arise from the differences between the train cab and the car, bus, or truck cabs. On the other hand, professional drivers in some cases were found to utlize in-vehicle devices and monitoring cameras which had such an expensive cost, that could not be afforded by non-professional users.

4 Review of post-trip interventions

As a first step of capturing the state-of-the-art regarding post-trip interventions, currently available systems, technologies, applications and schemes have been identified, with a focus on changing driver behaviour and enhancing knowledge, attitudes, perception and eventually safety performance. The intervention tools provide information, guidance and notifications to drivers via smartphones or web-based platforms. The possibility for after-market installation is also discussed as it is important to know what technologies could possibly be installed as part of i-DREAMS pilot testing.

4.1 Technologies utilized in post-trip interventions

The ultimate goal of this part of the deliverable is to learn more about intervention approaches to promote road safety and eco-efficiency in an occupational context. The focus is given on professional as well as non-professional drivers, so as to gain more insight into the effectiveness of intervention approaches that are implemented in a pre- or post-trip setting (i.e. outside the trip context, thus not triggered in real-time while driving). Reference is also made to work that relates to other transport modes. For instance, it is important to examine if post-trip intervention approaches that are applicable to professional truck operators might also apply to operators of other vehicle types.

4.1.1 Smartphone applications

Technological progress, especially in telematics, provided new potential for driver monitoring through smartphones. Smartphones have a wide array of sensors, such as accelerometer, compass, gyroscope, GPS, microphone and camera that enable sensing applications, even without user engagement. Smartphone technology is a good and efficient platform for driver behavior detecting and monitoring systems (Chaovalit et al., 2014). Several safe and eco-driving applications have been identified and a standardized survey was sent to the developers to better understand the features and interventions modalities. The majority of applications are designed to detect harsh events and mobile phone use, predict risk, analyse sensors data and performance's score and identify driver behaviour and transportation mode. (Amodo, 2019; Cmtelematics, 2019; Gotruemotion, 2019; Octotelematics, 2019; Oseven, 2019; Sentiance, 2019; Thefloow, 2019; Vivadrive, 2019; Zendrive, 2019). Oseven, for example, uses advanced machine learning techniques to exploit the recorded smartphone sensor data. An example of the mobile application of Oseven is presented in Figure 27. Trip details such as harsh accelerations and brakings, mobile phone use, speeding, or driving during rush or risky night hours are then provided to the user.

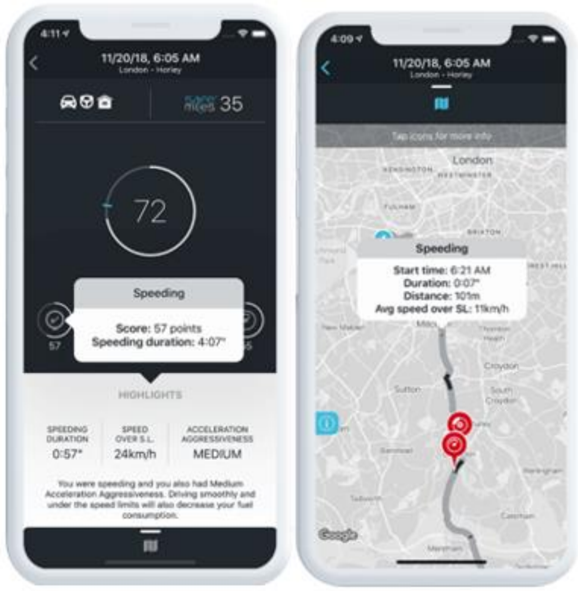

Figure 27: Oseven mobile application (Oseven, 2019)

4.1.2 Web-based platforms

Post-trip intervention and feedback using web platforms has been recently investigated in many studies (Toledo et al., 2008b; Farmer et al., 2010; Takeda et al., 2012; Braun et al., 2015). Using post-trip intervention technology, big data and machine learning algorithms, drivers could reliably quantify the risk associated with a specific driving behaviour such as speeding, number and severity of harsh events (braking and acceleration), harsh cornerings even or driving aggressiveness. Some examples of telematic recording web-based platforms providing post-trip feedback and driving characteristics are Sky-meter, OnStar, Freematics, MyRate device, IVDR system as well as GPRS-based technology. For instance, the online web-based platform of Oseven is presented in Figure 28.

Figure 28: Oseven web-based platform (Oseven, 2019)

4.2 Mode-specific literature review

This section provides the results of a transportation mode-specific literature review which aimed to investigate the utilization of post-trip interventions in cars, trucks, buses and trains. The targeted risk factors, the technical equipment, the corresponding intrusiveness and reliability of the smartphone applications and web-platforms as well as an overall assessment and recommendations for the i-DREAMS systems are described. Literature was searched within popular scientific databases such as Scopus, ScienceDirect, PubMed and Google Scholar. Examples of key words used per factor analysed, as well as the number of screened and included papers are given on Table 10.

Table 10: Key words, screened and included papers per factor analysed

Mode	Key words	Screened papers	Included papers
Cars	"post trip intervention technology" OR "post trip feedback" OR "feedback" OR "interventions" OR "feedback technology" AND "cars" AND "car drivers"	175	20
Trains	"rail driver" OR "rail operator" OR "train driver" OR "train operator" OR "tram driver" OR "tram operator" AND "intervention" AND "reflection" AND "learning" AND "training"	2,343	2
Buses	“post-trip interventions” OR “post-trip feedback” OR “feedback” OR “interventions” OR “telematics” OR “feedback technology” AND “bus” AND “coach” AND “bus driver” AND “coach driver”	56	7
Trucks	"eco driving truck app" OR "safety app trucks" OR "mobile app trucks" OR "trucks safety app feedback" OR "trucks eco driving apps" OR "eco driving truck app" OR "truck mobile app eco" OR "mobile app truck monitoring and feedback" OR "eco driving for truckers app" OR "driving behaviour apps truck" OR "trucker apps eco" OR "trucker apps driving behaviour" OR "apps driving behaviour trucker" OR "safe driving app truck" OR "trucker apps safe driving" OR "feedback app trucks" OR "trucker apps feedback" OR "trucker feedback eco driving" OR "trucker feedback eco driving app" OR "safe driving truck apps" OR "apps for truckers eco driving" OR "telematics trucks" OR "truck coaching app" OR "analysis driving behaviour lkw" OR "truck telematic driving behaviour" OR "truck performance logger" OR "truck driver behaviour app" OR "truck behaviour feedback" OR "truck driver behaviour feedback" OR "truck driver behaviour" OR "TRIMBLE" OR "renault" OR "vehco" OR "transics" OR "DAF" OR "MAN truck app" OR "PACCAR mobile app" OR "IVECO" OR "Hino" OR "Volvo trucks" OR "Dongfeng trucks" OR "Daimler group" OR "Scania app" OR "Fleetboard Driver Mercedes"	44	17

4.2.1 Cars

In this section, more specifically describes the availability of already commercialized solutions that monitor driver behaviour of car operators, and provide persuasive feedback, in a post-trip setting in order to promote a safe and eco-efficient driving style. There was a multiplicity and diversity of several research studies accumulated in modern literature according to post-trip interventions and drivers' feedback. The technologies and these kinds of feedback which seemed to provide satisfaction and acceptance to car drivers were also investigated.

Many reviews proved that there was a strong motivation for drivers to improve their driving style, differentiate their travel behaviour from aggressive to normal and reduce their degree of exposure by receiving post-trip interventions and monitoring their driving performance

(Tselentis et al., 2017; Kirushanth and Kabaso, 2018). Freematics, Sky-meter, OnStar and MyRate devices were the most effective technologies to provide feedback and encourage drivers for a safer behaviour. In addition, BCALs and IVDR such as DriveDiagnostics system, found to have high performance and relatively low cost. Web-based feedback systems such as PAYD found to be less effective as the awareness of being monitored faded as time passed and speeding returned to its 'natural' level. Finally, web-based Trip Diaries and Geotab GO6 system were unclear with regards to the outcomes translated into reduced near-crashes and crashes. Oseven, Zen Drive, True Motion, The Floow, Sentiance, Octo Telematics and VivaDrive were the most reliable smartphone applications which were evaluated for their acceptance and effectiveness. Smartphone applications were found to offer a cheap, scalable, and easily implementable alternative to current road monitoring methods, although several methodological challenges still remain. Table 11 gives an overview on post-trip intervention technology found in the literature to apply to cars and Table 12 summarizes the assessment of mobile applications providing post-trip feedback.

Table 11: Overview of studies concerned with post-trip interventions in cars and their assessment

Year	Authors	Risk factors	Indicators	Technical equipment	Type of feedback	Assesment	Acceptance/Effectiveness
2017	Tselentis et al.	crash risk	SP, distance, time, location, acceleration, deceleration, seatbelt use	Freematics, Sky-meter, OnStar, MyRate device, UBI, PAYD, PHYD, GPS, USB port, GPRS/CDMA, Bluetooth, SPP / OBD	V	🟢	feedback about speeding is effective at encouraging drivers
2017	Payyanadan et al.	crash risk, self-regulation	SP, distance, time, acceleration, braking	web-based Trip Diaries, Geotab GO6 /OBD, NDE	V	🔴	reduction of estimated route risk, but it is unclear whether the outcomes translated into reduced near-crashes and crashes
2015	Dijksterhuis et al.	distraction, risky driving behaviour	SP, steering, harsh brake, acceleration	PAYD system, web-based feedback system, three front facing screens /DS	V	🟡	broad PAYD insurance reduced the presence of risky behaviours during driving but the effects of PAYD only lasted while drivers earned rewards
2014	Newnam et al.	speeding performance	SP, average kilometres	GPS, GPRS network /DS,OBD	V	🔴	inconsistent pattern of speeding behaviour throughout the implementation of the feedback and goal setting exercises
2012	Roberts et al.	distraction	driving errors, attention, eye movements, head-tracking, unsafe glances, lane departure, collision	post-drive mitigation system, screen, distracted driving score, /SP, DS	V	🟢	effective tool to promote safe driving behaviour
2012	Ando and Nishihori	eco-safe driving	steep acceleration, deceleration, handling, time, distance, longitude, latitude	BCALs, GPS, Internet, radar chart /SP,NDE	V	🟢	high performance and low cost
2011	Bolderdijk et al.	driver performance	speeding	GPS device /NDE	V	🟡	PAYD was effective in reducing speeding across all road types but less effective at 30 and 120 km/h roads, awareness of being monitored faded as time passed and speeding returned to its ‘natural’ level
2011	Teng et al.	traffic safety, road navigation	SP	CAN-Bus, OZEN 1610, ECU /DS, SP, OBD	V	🟡	drivers monitor the car's information effectively
2008	Toledo et al.	driving performance	SP, acceleration, position, maneuvers, start/end time, location	DriveDiagnostics system, IVDR / SP,OBD	V	🟢	relatively cheap and continuous measurement of on-road driving behavior and vehicle usage

2008	Donmez et al.	driver inattention	speeding, acceleration, braking, TTC	touch-screen LCD, Global Sim Inc.'s DriveSafetyTM, camera / DS	V	●	drivers became more comfortable performing the task
2006	Toledo and Lotan	driving performance	SP, acceleration, position, vehicle location, time, maneuvers, fuel consumption	DriveDiagnostics system, IVDR, web pages / OBD	V	●	useful in moderating driving behavior, acceptance and frequent use of feedback can be encouraged by an interface that is aesthetically pleasing and easy to use

where OBD: On-Board Diagnostics, DS: Driving Simulator, P: Patent, SP: Smart Phones, NDE: Naturalistic Driving Experiment, FS: Field Study, V: Visual,
Assessment in terms of Acceptance/Effectiveness: ●: High, ●: Medium, ●: Low.

Table 12: Mobile applications for post-trip intervention for cars

Mobile application	Collision	Events (speeding, harsh braking/acceleration)	Eco-driving	Mobile phone use	Score	Assesment	Acceptance/Effectiveness
Oseven /SS	✓	✓	✓	✓	✓	●	driving behaviour analysis and scoring, eco scoring, recognize the transportation mode (car, motorcycle, and mass transit), driver/passenger identification, provide spatiotemporal analysis of the driving data, detect severe crashes, offers a set of user engagement tools and competitions
Zen Drive /SS	✓	✓	✓	✓		●	notifications via smartphone of collisions, risk analysis and a guide to coach drivers for sustained improvement
True Motion /SS	✓	✓		✓	✓	●	driver identification and transportation mode, measure location, road type, traffic and weather conditions, crash identification, impact location, airbag deployment
The Floow /SS, OBD		✓		✓	✓	●	driver/passenger identification, the journey scores are visible to the insurance company and integrated into the web-portal. Through a series of phone conversations, also the driver is helped to focus on ways to improve his overall score and to drive safely
Sentiance /SS, WS	✓	✓		✓	✓	●	trip details are visualized through the smartphone application and portal, transport mode classification, home/work detection, semantic time modelling, detect and predict personal context based on the user's current situation and historical patterns, roadside assistance
Octo Telematics /SS	✓	✓		✓	✓	●	theft prevention, stolen vehicle recovery, driver assistance, engage customers in active risk reduction with alerts and notifications via the smartphone application, drivers can find their car via the application or web portal with location-based services
Amodo /SS		✓		✓	✓	●	driving behavior, risk exposure, daily activity levels ,identification of transportation mode

Cambridge Mobile Telematics /SS	✓	✓		✓	✓	●	trip details available to the user via smartphone application or web platform, driver/passenger classification, vehicle identification
VivaDrive /SS,OBD		✓		✓		●	engagement campaigns organized with program partners, engaging challenges based on different criteria (driving, business, lifestyle), badges and levels to recognize user and customers achievements; leaderboards to drive and encourage competition, meaningful for drivers to spot risky driving behaviours and stay motivated to improve their safety on the road
GAFU /SS,OBD		✓	✓		✓	●	the system evaluates the driving style from the viewpoint of energy efficiency, encourage drivers to change their driving habits and reduce fuel consumption
where: OBD: On-Board Diagnostics, SS: Smartphone Sensor, WS: Wearable Sensor, **Assessment** in terms of Acceptance/Effectiveness: ●: High, ●: Medium.							

4.2.2 Trucks

In order to be able to get a more valid view on the effectiveness of interventions combining in-vehicle behavioural monitoring with post-trip feedback, a structured literature review was conducted. For this review, the focus was more specifically on intervention programs aimed at promoting road safety, since road safety remains the key-interest of the i-DREAMS project.

In general, it was found that truck-specific systems pay a great deal of attention to eco-driving. Although safety is also a relevant topic. To this end, multiple parameters are being logged. The focus on these parameters, however, can differ greatly between systems. The logged parameters are not only being used to monitor drivers, but also to provide feedback to the management/coach, and in most cases, also to drivers. Post-trip feedback alone was provided by five systems. The combination of both real-time and post-trip feedback was more prevalent, as provided by several systems. Gamification as a behaviour change strategy is already employed in several systems, although not always with the same focus or to the same extent. For instance, some companies decided to provide material/financial rewards, while others provided tips or access to social networks. Most of the times, feedback going beyond access to monitoring results required a company middle-man, for instance someone from the management or a coach, that will discuss the results with the driver in order to provide coaching. Direct and automated coaching from the application was less common.

Technical descriptions are provided per truck-specific system for the two categories that were identified: post-trip feedback and a combinations of real-time and post-trip feedback. Table 13 contains a summary of the application analyses targeting driving behaviour (safety and/or eco) in truck drivers while providing post-trip feedback to the driver as well as Table 14 provides a summary of the application analyses targeting driving behaviour (safety and/or eco) in truck drivers while providing combined real-time and post-trip feedback. It is worth mentioning that no distinction was made between points and scores, rather, a general category was opted for scores.

Table 13: Summary of the application analyses targeting driving behaviour (safety and/or eco) in truck drivers while providing post-trip feedback, no distinction was made between points and scores, rather, a general category was opted for scores

Application	Parameters (indicators)	Signal input	Feedback to driver?	Behaviour change (incl. gamification) & comments
D2go	Accident (possible accident) Seatbelt use Steering (harsh cornering) Speed (exceeding limit) Acceleration (hard acceleration) Braking (harsh braking) Engine (engine abuse, light on) Idling	Geotab	Accident Seatbelt use Steering Speed Acceleration Braking Engine Idling Weekly & quarterly trend analysis	Coach involvement Driver dashboards Goals (+weights) Scores Levels Badges & medals Leaderboards Performance & progress graphs Report cards Material & financial rewards (optional)
DAF Connect	Braking (braking behaviour, anticipation) Speed Idling Fuel	Open platform using rFMS standard	If sent by management Optional predetermined events (e.g. deviations in speed, route, location)	Management dashboard Driver comparison (possible to receive alerts for drivers) Real-time reports to drivers (optional) If necessary, management can: -Offer DAF EcoDrive+ -Offer awareness raising
NEXT driver	Harsh acceleration events (acceleration, gas pedal angle, RPM) Braking (# of events) Signalling your intentions Lane discipline Manage following distance Coasting (distance spent coasting vs total distance based, compared to expected coasting time) Speed (# of overspeeding events, time above limit) Cruise control Average brake counter (levels: high, low, soft), compared to expected # of braking events) Deceleration/ Acceleration (< –1,6 m/s^2)	FMS-provider Own device sensor	Harsh acceleration events Braking Signalling your intentions Lane discipline Manage following distance Coasting Speed Cruise control time Average brake counter Deceleration Acceleration	Weekly reports Scores (1.0-10.0) Progress graph App-based methods in active development (achievements, team competition) Automatic in-app feedback texts Medium/low-frequency WhatsApp coaching for 20% worst drivers & compliments for 10% best
Scania Fleet Management	Gear shifting Anticipation (braking) Coasting Speeding Cruise control Idling Hill driving	rFMS	Gear shifting Anticipation (braking) Coasting Speeding Idling Hill driving	Portal for management Scores Performance & progress graphs Tips Driver profiles Reports Monitoring package (management only?): weekly, monthly, and annual reports via mail

Truck Hero	Acceleration (hard acceleration) Steering (hard cornering) Braking (hard braking) Speed (speed monitoring, over bumps) Coasting (rolling out) Cruise control Idling (idling during stops) Fuel usage (Fuelsave tracks, e.g., driving with full load, idling, ...; Fuelprotect monitors fuel levels in the tank and alerts in case of theft)	Track & trace Dashcam (optional) FMS Transport intelligence platform (in: vehicle data, out: intelligence)	Acceleration Steering Braking Speed Video material if dashcam is present Others?	Online management dashboard & Truck hero app (coaches drivers) Tips Leaderboards Performance indicators Indication (smartphone) & recall of alerts/events Improvements (or not) indicated in % Fleetbotbeta allows to receive notifications

Table 14: Summary of the application analyses targeting driving behaviour (safety and/or eco) in truck drivers while providing combined real-time and post-trip feedback, no distinction was made between points and scores, rather, a general category was opted for scores

Application	Parameters (indicators)	Signal input	Feedback to driver?	Behaviour change (incl. gamification) & comments
DKV Eco Driving	Acceleration (strong acceleration) Braking (hard braking) Avoid getting stuck in traffic (GPS based navigating) Speed (limits indication, comparison speed with limit) Economic refuelling (based on distance & fuel prices)	Tablet Gyroscope	Acceleration Braking Avoid getting stuck in traffic Speeding Economic refuelling	Scores Score boards Material rewards
Dynafleet app	Coasting Average brake counter Average stop counter Within Economy time Above Economy time Top gear time Engine load time I-shift (in Automatic time, in Manual time, in Power time) Speed (average speed, time above limit) Cruise control Idling	CAN	Coasting Average brake counter Average stop counter Within Economy time Above Economy time Top gear time Engine load time I-shift Speed Cruise control Idling	Coach involvement Reports Scores
Fleetboard Driver.app	Fatigue prevention (drive, rest, weekly drive times) Braking Speed	Fleetboard Digital tachograph (DTCO)	Fatigue prevention Braking Speed Idling	Reports Scores (My Grade, scoring system: 1-10) Tips Leaderboards

	Idling (stop times with engine running) Fuel (consumption) EcoRoll (manipulates coasting, optional with certain trucks) Trailer ID (identification, coupling status, tracking		Fuel Real-time (optical & acoustic, only for fatigue) Post-trip (direct feedback on driving style & results of last 12 journeys + individual reviews)	Addition of other functions -Communication (buddy's & networks) -Leisure (e.g. fitness)
Frotcom	Acceleration Speed Cruise control Braking (harsh braking) RPM Overreving Engine (temperature) Automatic driver identification	App CAN	Acceleration Speed Cruise control Braking RPM Overreving Engine	Driver feedback bar allows to give direct & immediate feedback Score (general?) Weight selection Score outcome allows to train, measure, reward and coach your drivers (not via app)
IVECONNECT	Attention (detects steering wheel movements & signals drops in attention) Steering (LDWS (lane departures)) Gear shifting Braking (EBS/BAS/AEBS) Anticipation (inertia, deceleration, braking frequency)	Engine Vehicle GPS	Real-time -Attention (acoustic & visual) - On-screen graphics (8 parameters) -Tips for reducing fuel consumption Post-trip (end of mission) Attention Steering Gear shifting Braking Anticipation	After each mission, the report can be verified directly from the DSE menu (0-5 evaluation) & previous missions can be accessed ECO switch (limits top cruising speed & optimizes drive line performance)
Omnitracs	Attention/distraction (facial tracking) Eating/drinking (facial tracking) Steering Reversing Gear shifting Adjusting to weather & road conditions (weather apps integration in Nav System) Avoid getting stuck in traffic (traffic integration in Nav System) Lane discipline (camera also using GPS & lane data)	On-board device In-cab device Camera Phone GPS Nav GPS Cellular OBD	Attention/distraction Eating/drinking Acceleration Speed (average speed, time above limit) Idling	Driver coaching with their supervisor Summarized reports Scorecards for posting of leaders and trends

	Traffic lights (road data) Stop signs (road data) Right-of-way (road data) Seat belt use Parking Brake Coasting (neutral or zero acceleration) Acceleration Speed (exceeding limit/time above limit, average speed, adequate speed for circumstances, limits indication) Braking (average brake counter, average stop counter) Deceleration Above economy time Top gear time Overreving Engine load time Idling			
Trimble Performance Portal	Fatigue prevention (driving & rest time) Aggressive driving Speed Acceleration (rapid acceleration) Braking Turning (harsh turning) Cruise control Idling (stationary behaviour) Infringement manager (automatic infringement calculation) Fuel irregularities (fuel efficiency)	Tachotime Manage FMS GPS	Fatigue (on-board driving-time assistant) Aggressive driving Speed Acceleration Braking Turning High fuel consumption Real-time (audible & visual alerts (optional) Post-trip (last 7 days)	2 optional modules Management KPI dashboard (1) Coach Assistant (2) --> calculates daily maximum score day (Onboard Driver Scorecard) & advises coach how drivers can reach better score Leaderboard Reports Intervention logbook
TX-ECO	Gear shifting (graphic representation of distribution over the single gears; no of gear shifts / 100km, absolute no. of gear shifts) Acceleration (time & distance without acceleration pressed) Speed (average speed, exceeding limit/time over limit, limits indication) Cruise control (% cruising of trip duration; distance in cruise control mode in km (absolute & relative))	GPS	Acceleration Gear shifting Speed Cruise control Coasting Anticipation Braking Top gear time RPM (average) Overreving	Real-time: Driver gets scores (bonus-malus) throughout the drive and can see status of scores on display in cabin. No rewards are attached. Real-time feedback can be customized, e.g. "Drive defensively!" or “Turn off engine when parked!”

	Coasting Anticipation (m/s2) Braking (harsh breaking ("panic breaking) no./100km) Top gear time (graphic representation of distribution over the all gears) RPM (average) Overreving Engine load time (% of trip duration in green, yellow and red zone (% engine load combined with RPM)) EBS Red warning alarm EBS Roll stability alarm Idling (absolute time (s) per idling episode and relative (% of total trip length))		Engine load time EBS Red warning alarm EBS Roll stability alarm Idling Post-trip (only if employer requested)	
Vehco Mobile	Fatigue prevention (Drive- and resting Times, (advance) violation warning, write explanation if/when violations occur) Avoid getting stuck in traffic (traffic density in maps, allows for manager assistance in route selection) Defensive driving (eco-driving service with specific index) Driving when angry (eco) Stop signs (planning through Eco-Driving) Safe distance (planning through Eco-Driving) Coasting Speed as part of Eco-Driving (speed, exceeding limit/time over limit) Braking ("wasted energy", average brake counter, harsh braking) Deceleration (retardation) Idling	Tacho; D8 + legal files (C1b/DDD-files) CAN/FMS gateway Google etc.	Fatigue prevention Avoid getting stuck in traffic Braking Defensive driving Exceeding speed limit Post-trip (report generated by office application)	Reports Progress graphs Personal/team challenges/goals can be implemented Use of pedagogic ways to motivate/make it easy for the driver to understand how to Eco-Drive. Eco-Driving Index: -Green/Yellow/Red colours and relative measures (%) so that everyone (drivers, groups and companies) can be compared. - Encourage all customers to participate in an Eco-Driving Challenge.
WaySmart	Aggression (linear acceleration criteria fail time and g-force) Event detection/alert (crash & rollover, violation) Hazards (allows driver communication hazards) Seatbelt Steering (lane deviations)	CAN Kinematic sensors Network data Accelerometers GPS Lane tracker	Aggression Event detection/alerts Speed Seatbelt Fuel	Online management portal (allows to select violations) Driver & fleet scorecards (identify who needs training) Performance & progress graphs Manager reports (weekly or flag events in real-time)

	Acceleration (sudden longitudinal acceleration) Braking (hard braking, time-to-collision) Speed (vehicle speed more than 5 mi/h (8.0 km/h) above limit, limits indication) Overreving RPM Idling Fuel (fuel use & MPG tracking) Other: turn signal use, other vehicle info, continuous audio	Yaw rate Black box technology	Post-trip (previous week, month, or year)	

4.2.3 Buses

In order to change and improve the behaviour, a deep knowledge relating to professional bus drivers' attitudes, perception and performance concerning economy and safety binomial is required. Thus, a competitive and increasingly open access business demanded for the development of telematics systems that were able to collect, log and process vehicle and driving style-related data into simple performance analysis for fleet managers. End-of-trip and post trip performance evaluation and feedback are key to develop a proper driver training and coaching program that leads to a visible and lasting impact on professional drivers' safety and efficiency related driving behaviours. With this precious intel in hands, fleet and operations managers are able to employ data-driven methodologies to adequately select vehicles and drivers for specific journeys, as well as develop tailored training programs to address the insights unveiled by telematics systems.

Since the development of such tools is obviously driven by market demand, considering the abundancy and size of light and heavy goods commercial vehicle fleets, most systems available to buses were first introduced to trucks and thereby won't be described in detail within this section. In particular, the tools and systems listed are examples of solutions commonly employed by both heavy goods and passenger vehicle fleets to monitor and evaluate driver behaviour and fleet performance and thereby to provide post-trip insights regarding compliance and adequate driver behaviour and identify areas in need of improvement.

There is an often strong, almost umbilical, relationship between systems and tools that continuously monitor driving and vehicle parameters with intent to provide drivers with real-time feedback, on their performance and driving style, and those that have some or several forms of post-trip information, data or records. The realisation that driver's acceptance of post trip feedback and engagement is strongly reinforced by real-time feedback, most systems that initially focused on post-trip feedback and training have been deploying additional modules and services to complement the base telematics system with real-time in-vehicle feedback. Hence, many of the systems hereby described are coincident and have already been previously mentioned, within the real time interventions section. As in the case of real-time interventions for buses, eco-driving is not part of the most intervnetions, while information is missing on how the drivers accept interventions provided by the fleet and operations managers. Green Telematics and Scania Optimile Fleet Management interventions systems were found to be the most comprehensive for practical implementation.Table 15 reveals an overview of studies concerned with post-trip interventions in buses and their assessment.

Table 15: Overview of studies concerned with post-trip interventions in buses and their assessment

Solution/Product	Type of data	Indicators	Assesment	Type of feedback
Scania OptiMile and Fleet Management	vehicle can bus data, web-based portal, individual scores	gear shifting, braking, coasting, speeding, cruise control, idling, hill driving	●	V
GreenRoad BUS Telematics	in-vehicle video system, safety driving scores, gamification strategies	wear, tear, keeping track of service times, and monitoring health, safety performance, risky evets	●	V
Driveprofiler	nomadic devices (smartphones and tablets), OBD II, in-vehicle device. CAN-bus	harsh longitudinal, lateral accelerations, contextual overspeeding, road type, layout classification, intersection count, lane changing, time of day, week driving periods, weather pattern, risk scoring	●	V
Jaltest Telematics	web-based portal, detailed reports	acceleration, braking, overriding, overspeeding, coasting, usage of primary and auxiliary braking systems, idle times, fuel consumption	●	V
Pure Telematics	driver scoring tool, frontal vídeo camera integration / dash cam	speeding, stop tracking, idling, acceleration patterns and fuel consumption data	●	V
Stratio Automotive	machine learning techniques, CAN bus or FMS bus connection, inertial sensors	acceleration and braking patterns, speed engine, proper use of gearbox, coasting, fuel efficiency	●	V
FuelSave	CAN and FMS bus connection	fuel efficiency	●	V
where OBD: On-Board Diagnostics, V: Visual, **Assessment** in terms of Acceptance/Effectiveness: ●: High, ●: Medium.				

4.2.4 Trains

Several studies for railway post-trip interventions were investigated. The results proved that there was not a diversity of technologies and systems, provided feedback to truck drivers, as only two relevant studies were examined. Such a paucity of studies was anticipated given both post-trip interventions and the rail domain in general were known to be under researched. Neither of the two relevant studies gave detailed findings on a post-trip intervention but instead theorise how a gamified application could work in the rail industry. The first details showed how such an app could be designed to adhere to motivating principles. The second study justified why real time or post-trip feedback would be needed and why simply monitoring energy consumption would not be sufficient to have a long-term significant effect on train drivers' behaviour and thus energy usage.

To sum up, it should be mentioned that there was not a separation between visual, auditory or haptic post-trip interventions for trains as in the studies investigated. Actual post-trip feedback was not found to have been provided to the driver and no intervention had actually being tested. Table 16 reveals the review of the studies for post-trip intervention for trains.

Table 16: Overview of studies concerned with post-trip interventions in trains and their assessment

Year	Authors	Indicators	Technology	Assesment
2017	Bartnik and Ćwil	energy consumption	'Placebo' test, app	●
2016	Ćwil and Bartnik	fuel use	Self Determination Theory, app	●
Assessment in terms of Acceptance/Effectiveness: ●: Low.				

4.3 Summary

4.3.1 Intermodal considerations for the i-DREAMS platform

As demonstrated in the previous subsections, post-trip feedback has the potential to affect long-term behavioural change. It would be very important to highlight which of the aforementioned post-trip interventions are more efficient to improve driver behaviour and promote road safety.

The effectiveness of post-trip intervention systems in cars depended on the appropriate reward or penalty systems used, system design and user acceptance. It was proved that the most effective and common feedback given to drivers after each trip were visual warning signals and textual alerts through SMS, e-mail or written reports with comments and proposals for better driving performance. A gamified environment also assists in gradually building up skills and keeps users motivated to operate their vehicle in a 'safety tolerant' way over a longer period of time.

Visual devices, in-vehicle cameras and smartphone applications had lower initial hurdles regarding acceptance and effectiveness in cars and trucks. It is worth mentioning that as of yet no post-trip interventions to improve train drivers' safety appear to have been developed or tested in the current literature.

As a result, with the exception of trains, in-vehicle devices with small size, web-gamified monitors and smartphones could be easily modified and transferred in order to provide drivers with post-trip feedback.

Most of the truck applications provided both real-time and post-trip interventions to drivers and sent them score boards, summarized reports, progress graph, in-app feedback texts, material rewards and other visual or haptic notifications. It was really interesting that in some cases the individual score of a professional fleet operator wasn't shown to the employer and the latter didn't have access to the progress of the whole group of drivers.

Consequently, the purpose of this section was to have a comprehensive depiction on which are the variables related to driver behaviour, which were targeted by web-gamified platforms and smartphone applications, which technologies provide these measurements and which measured indicators/parameters give useful information for post-trip interventions. Freematics, Sky-meter and OnStar were the most effective ways to provide feedback and encourage drivers for a safer behaviour. In addition, web-based feedback systems such as BCALs, post-drive mitigation systems and IVDR had high performance and relatively low cost. Smartphone applications such as Oseven, Zen Drive, The Floow, Octo Telematics and VivaDrive for cars as well as D2go, Truck Hero, Scania Fleet Management, NEXT driver and DAF Connect for trucks were the most reliable applications that were utilized providing post-trip feedback. Table 17 summarizes information with regards to operator behaviour and gives an overview of target factors, metrics and data collection tools for all transport modes of the i-DREAMS project. A detailed literature review of post-trip interventions is given in Appendix E.

Table 17: Overview of target factors, metrics and data collection tools with regards to post-trip interventions for all transport modes of i-DREAMS project

	Targeted at	Metrics	Applicability in *i*-DREAMS	Car	Bus	Truck	Train
Operator behaviour	driving performance	speed, distance, time, location, acceleration, engine RPM	•	Freematics/Bluetooth/SPP			
	crash risk	SP, distance, time, location, acceleration, deceleration, seatbelt use	•	Sky-meter, OnStar /OBD			
	distraction	driving errors, attention, eye movements, head-tracking, unsafe glances, lane departure, collision	•	post-drive mitigation system, screen, distracted driving score, /SP, DS			
	driving performance	SP, acceleration, position, maneuvers, start/end time, location	•	DriveDiagnostics system, IVDR / SP,OBD			
	eco-safe driving	longitude, latitude, time, acceleration/deceleration/ handling, distance	•	BCALs/SP/NDE			
	driving performance	speeding, harsh braking, harsh accelerations, driver phone use, average distance per trip, average trips per driver, distance per road type	•	Oseven/AP			
	eco-safe driving	speeding, harsh braking, accelerations, phone use, road conditions and types, miles driven, time of day, fuel used	•	Zen Drive /AP			
	driving performance	SP, acceleration, braking, cornering, distraction, fatigue, time of day	•	The Floow /AP, OBD			
	driving performance	SP, location, cornering, braking, trip duration, road type, distance, direction, night driving, frequent hard breaking, frequent hard acceleration, distraction (mobile use)	•	Octo Telematics /AP			

	driving performance	speeding, braking, acceleration, mobile use and reckless events (night driving, rush hours)	•	VivaDrive/AP/OBD			
	driving performance	wear, tear, keeping track of service times, and monitoring health, safety performance, risky evets	•		GreenRoad BUS Telematics/in-vehicle video system		
	driving performance	harsh longitudinal, lateral accelerations, contextual overspeeding, road type, layout classification, intersection count, lane changing, time of day, week driving periods, weather pattern, risk scoring	•		Driveprofiler/nomadic devices (smartphones and tablets), OBD, in-vehicle device. CAN-bus		
	driving performance	acceleration, braking, overreving, overspeeding, coasting, usage of primary and auxiliary braking systems, idle times, fuel consumption	•		Jaltest Telematics/web-based portal		
	driving performance	speeding, stop tracking, idling, acceleration patterns and fuel consumption data	•		Pure Telematics/ frontal vídeo camera integration / dash cam		
	driver vehicle inspection reporting, driver identification	possible accident, steering, speed, acceleration, braking, engine, seatbelt use, idling	•			D2go/AP/OBD	
	driving performance	acceleration, braking, steering, excessive speed, coasting, cruise control, idling, fuel usage, rolling without the use of gas	•			Truck Hero/AP/OBD	
	driver/vehicle evaluation	gear shifting, braking, coasting, speeding, cruise control, idling, hill driving	•			Scania Fleet Management/AP	
	driving behaviour	harsh acceleration, braking, lane discipline, following distance, coasting, speed, cruise control time, average brake counter	•			NEXT driver/AP/OBD	

[redacted]	driving performance	braking, speed, fuel, idling	🟢			DAF Connect/AP/OBD	
	driving performance	energy/fuel use	🔴				Self Determination Theory/SP
	driving performance	energy consumption	🔴				Placebo test/NDE/SP

where OBD: On Board Diagnostics, SP: Smart Phones, AP: Application, DS: Driving Simulator, NDE: Naturalistic Driving Experiment,
Assessment in terms of Acceptance/Effectiveness: 🟢: High, 🔴: Low.

4.3.2 Considerations of differences between professional and non-professional drivers

According to the literature investigated, a diversity of technologies was revealed in order to provide post-trip interventions. The results of the evaluation showed that textual driver feedback was perceived as more helpful than the currently used forms of feedback. Smartphone applications that were utilized for cars can be used by professional drivers. Most of the car applications provided visual post-trip feedback to drivers that can easily be transferred to other transport modes as these were not intrusive and there is small risk of distraction for professional drivers during driving. Moreover, web-based platforms that were used for cars, were small devices inside the vehicle which were easy to utilize from truck or train drivers. Finally, the most common way providing post-trip interventions to drivers was via smartphone applications, which are easily transferrable due to their low cost for every vehicle operator.

4.3.2.1 Cross-modal conclusions

Naevestad et al. (2018) identified 8 factors that influence safety culture change. These factors are not entirely independent, rather, factors can overlap and can also influence each other. Similar to the original report, the eight factors are presented as general mode-overarching factors, with some added clarification in case they are actually more mode-specific (i.e. road, aviation, maritime, and rail). For the specific studies and references, it is important to refer back to Naevestad et al. (2018).

1. Top management commitment during the entire intervention period.
   Manager commitment was identified as an important factor in several studies and was relevant across all modes. Specific for rail transport, studies indicated the importance of strong leadership, sufficient management commitment, and absence of role confusion that decreases commitment visibility.

2. Engagement and support of employees.
   Employee engagement in the process of change and interventions measure(s) is key to safety culture change. Several studies also indicated that union cooperation can likely encourage the engagement of employees. Finally, according to a study in road transport (including cars and trucks), the effectiveness of group discussions for improving safety could be caused by employee engagement in risk analysis and subsequent execution of action plans.

3. Manager and employee relationship.
   Two studies in rail transport indicated the importance of the manager-employee relationship. Several impeding factors were mentioned, i.e. trust, resistance in experienced employees, and an unjust culture.

4. Motivation for the intervention.
   A strong motivation, or high need, is important for successful safety interventions (e.g. a lot of dangerous incidents, poor safety culture). In this regard, effects should be communicated in line of the reasons behind the intervention. Specific for car drivers, intervention motivations can differ in case of business drives, for which motivations often relate to benefits of increased productivity.

5. Focus of regulatory authorities on safety (culture) and company support.

Some promising studies indicated the importance of a regulatory focus on (safety) culture as a motivating factor for interventions. However, in one study, standalone regulatory focus was insufficient. Moreover, some other interventions were not motivated by such a regulatory focus.

6. A clear and congruent intervention implementation.
   The necessity for a clear and congruent intervention was derived from cases targeting different modes that indicated the importance of clear implementation (rail), avoiding complicated procedures (maritime), and interventions that are, besides being coherent and structured, congruent with existing systems (road).

7. Attention taken away from the intervention by reorganization or other processes.
   Reorganizations were found to negatively affect the intervention in some studies. For instance, when managers related to the intervention implementation were replaced.

8. Intervention content.

The content of the intervention, e.g. activities and goals, is a very important factor that influences the motivation of employees to participate.

5 Conclusions and considerations about technologies for safety interventions

This deliverable aimed at critically overviewing the state-of-the-art in intervention technologies for driving safety and at providing recommendations for the most effective ones to be used under a simulator or naturalistic driving experiment. The importance of a correct intervention was highlighted, and it was revealed that acceptance along with effectiveness should be the top priority in terms of choosing an appropriate intervention strategy. Furthemore, it was demonstrated that multi-stage provision of warning could become beneficial in terms of safety and minimum driving task load.

With regards to car-specific interventions, visual and auditory warnings were deemed more appropriate in real-time, while driver telematics with gamification features were found to perform better after a driving session. The results obtained with respect to trucks confirmed that although a combination of monitoring and gamified feedback resulted in the best driving behaviour during and after the trip, it was clearly mentioned that such interventions are not provided in isolation. It is important to keep in mind that this kind of feedback is usually imbedded within a broader safety change intervention framework in which they are offered in combination with other strategies (i.e. driver coaching and management commitment and support). Therefore, a focus on individual components will probably be insufficient to accomplish sufficient safety culture change. Moreover, little information was found on the acceptance of safety interventions from bus drivers, but advantages for fleet operators were visible in terms of continuous vehicle surveillance and driver compliance to traffic rules. Train interventions operate in a different regime, but evidence from the literature demonstrated that auditory and visual warning could enhance driver alertness in real-time. Transferability of interventions was not found to be troublesome in most of the technologies, apart from the train-specific ones, and thus the i-DREAMS intervention strategy could achieve a cross-modal form.

Based on the list of intervention technologies listed for each mode, as well as the legislative and behaviour theoretical principles outlined in the deliverable, the i-DREAMS consortium could identify the ones, better in-line with the expected results. Priority should be given to the form of feedback, as well as the integration with the existing web-platforms and sensor equipment included in the trials. With regards to real-time interventions, attention should be given on the exploitation of the sensors inside each vehicle so as to capture all the necessary aspects required for operator state enhancement and coaching. The post-trip intervention platform should not at fully replace other intervention approaches but should act as a complement to other actions taken to improve road safety and eco-efficiency. Both real-time and post-trip interventions should nevertheless be designed according to the principles of persuasive technology.

As a final remark, it should be mentioned that the interventions will be triggered based on the estimation of the STZ. More specifically, real-time interventions would be triggered based on specific indication of the safety level of the environment, and hence, the selected interventions should be versatile and quick in providing feedback, but simultaneously should aim at being as less obtrusive and distractive as possible. Simultaneously, the development of the STZ model should estimate the mode-specific and operator-specific thresholds for triggering and accepting feedback from such interventions, so as to maximize the effect on safety among all traffic participants.

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Annex A: Overview of legal framework for professional driver qualifications

DIRECTIVE 2006/126/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 20 December 2006 on driving licences (Recast)	DIRECTIVE 2003/59/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 15 July 2003 on the initial qualification and periodic training of drivers of certain road vehicles for the carriage of goods or passengers, amending Council Regulation (EEC) No 3820/85 and Council Directive 91/439/EEC and repealing Council Directive 76/914/EEC	DIRECTIVE (EU) 2018/645 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 18 April 2018 amending Directive 2003/59/EC on the initial qualification and periodic training of drivers of certain road vehicles for the carriage of goods or passengers and Directive 2006/126/EC on driving licences
ANNEX II **I. Minimum requirements for driving tests** **A. THEORY TEST** **1. FORM** The form chosen shall be such as to make sure that the applicant has the required **knowledge** of the subjects listed below. **2. CONTENT OF THEORY TEST CONCERNING ALL VEHICLE CATEGORIES** 2.1 Questions must be asked on **each of the points listed below**, the content and form of the questions being left to the discretion of each Member State**:** • 2.1.1. Road traffic regulations; • 2.1.2. The driver; • 2.1.3. The road; • 2.1.4. Other road users; • 2.1.5. General rules and regulations and other matters;	**ARTICLE 3: QUALIFICATION & TRAINING** The activity of driving as defined in Article 1 (Scope) shall be subject to a compulsory initial qualification & compulsory periodic training. To this end Member States shall provide for: • A system of **initial qualification** where Member States shall choose between the following two options: o Combining **both course attendance and a test** (consisting of compulsory course attendance for specific period, concluded with a test) o **Only tests** (theoretical and practical) However, a Member State may authorise a driver to drive within its territory before obtaining a CPC, when he/she is undergoing a **national vocational training course of at least six months, for a max period of three years.** In the context of this vocational training course, the tests may be completed in stages; • A system of **periodic training** o **Compulsory** course attendance. Member States may also provide **a system of accelerated initial qualification** so that a driver may drive in the cases referred to in Article	

• 2.1.6. Precautions necessary when alighting from the vehicle;
• 2.1.7. Mechanical aspects with a bearing on road safety;
• 2.1.8. Vehicle safety equipment and, in particular, the use of seat-belts, head restraints and child safety equipment;
• 2.1.9. Rules regarding vehicle use in relation to the environment.
 	
4. SPECIFIC PROVISIONS CONCERNING CATEGORIES C, CE, C1, C1E, D, DE and D1E
4.1 Compulsory check of <u>**general knowledge**</u>
• 4.1.1. Rules on driving hours and rest periods as defined by Council Regulation (EEC) No 3820/85 of 20 December 1985; use of the recording equipment as defined by Council Regulation (EEC) No 3821/85 of 20 December 1985 on recording equipment in road transport;
• 4.1.2. Rules concerning the type of transport concerned;
• 4.1.3. Vehicle and transport documents required for the national and international carriage of goods and passengers;
• 4.1.4. How to behave in the event of an accident; knowledge of measures to be taken after an accident or similar occurrence, incl. emergency action such as evacuation of passengers and basic knowledge of first aid;
• 4.1.5. The precautions to be taken during the removal and replacement of wheels;
• 4.1.6. Rules on vehicle weights and dimensions; rules on speed limiters;
	5(2)(b). This involves **compulsory course attendance,** concluded with a **test**.
	
	ARTICLE 4: ACQUIRED RIGHTS
	The drivers referred to in Article 4(a) and (b) **shall be exempted** from the requirement to obtain an **initial qualification**.
	
	ARTICLE 5: INITIAL QUALIFICATION
	Access to an initial qualification shall **not require** the corresponding driving licence **to be obtained beforehand.** Drivers of a vehicle intended for the carriage of goods may drive:
	• from the **age of 18**: a vehicle in licence categories C and C+E, provided they hold a CPC as referred to in Article 6(1);
	• from the **age of 21:** a vehicle in licence categories C and C+E, provided they hold a CPC as referred to in Article 6(2).
	
	ARTICLE 6: CPC CERTIFYING THE INITIAL QUALIFICATION
	CPC certifying an <u>**initial qualification**</u>:
	• On the basis of **course attendance & test:**
	  o Member States shall require trainee drivers to attend courses in an '**approved training centre'**.
	  o These courses shall cover all subjects referred to in **section 1 of Annex I**.
	  o Training concludes with successful completion of the test provided for in **section 2(2.1) of Annex I.** Test shall be organised by the Member States' **competent authorities** or an entity designated by them.
	• On the basis of **tests**:
	  o Member States shall require trainee drivers to pass the **theoretical and practical tests referred to in section 2(2.2) of Annex I**. Tests shall be organised by Member States' **competent authorities** or an entity designated by them.	

• 4.1.7. Obstruction of the field of view caused by the characteristics of their vehicles; • 4.1.8. Reading a road map, route planning, including use of electronic navigation systems (optional); • 4.1.9. Safety factors relating to vehicle loading; 4.2 Compulsory check of general **knowledge** on following **additional provisions** • 4.2.1. Principles of the construction & functioning of: internal combustion engines, fluids, fuel system, electrical system, ignition system, transmission system; • 4.2.2. Lubrication and antifreeze protection; • 4.2.3. Principles of the construction, the fitting, correct use and care of tyres; • 4.2.4. Principles of the types, operation, main parts, connection, use and day-to-day maintenance of brake fittings and speed governors, and use of anti-lock brakes; • 4.2.6. Methods of locating causes of breakdowns; • 4.2.7. Preventive maintenance of vehicles and necessary running repairs; • 4.2.8. Driver's responsibility in respect of the receipt, carriage and delivery of goods in accordance with the agreed conditions. **B. TEST OF SKILLS & BEHAVIOUR:** **5. THE VEHICLE AND ITS EQUIPMENT** 5.1. The driving of a vehicle with manual transmission shall be subject to the passing of a skills and behaviour test taken on a **vehicle with manual transmission**.	Certifying **accelerated initial qualification:** • Member States shall require trainee drivers to attend courses in an **approved training centre**. Courses shall cover all the subjects referred to in **section 1 of Annex I.** • This training shall conclude with the **test** provided for in **section 3 of Annex I**. That test shall be organised by the Member States' **competent authorities** or an entity designated by them. **ARTICLE 7: PERIODIC TRAINING** Periodic training shall consist of training to enable holders of a CPC as referred to in Article 6 and the drivers referred to in Article 4 **to update the knowledge** which is essential for their work, with specific emphasis on **road safety and the rationalisation of fuel consumption**. Periodic training shall be designed **to expand on, and to revise,** some of the subjects referred in section 1 of Annex I.	**AMENDMENTS ARTICLE 7** Periodic training shall consist of training to enable holders of a CPC to update the knowledge which is essential for their work, with specific emphasis on road safety, **health and safety at work**, and the **reduction of the environmental impact of**

5.2. The vehicles used in tests of skills and behaviour shall comply with **<u>minimum criteria</u>** given below. • Category C: category C vehicle with a max authorised mass of at least 12 000 kg, a length of at least 8 m, a width of at least 2,40 m and capable of a speed of at least 80 km/h; fitted with anti-lock brakes, equipped with a gearbox having at least 8 forward ratios and recording equipment as defined by Regulation (EEC) No 3821/85; cargo compartment shall consist of a closed box body which is at least as wide and as high as the cab; the vehicle shall be presented with a minimum of 10 000 kg real total mass. **8. SKILLS AND BEHAVIOUR TO BE TESTED CONCERNING CATEGORIES C, CE, C1, C1E, D, DE, D1, D1E** 8.1. **<u>Preparation and technical check</u>** of the vehicle with a bearing on road safety. Applicants must demonstrate that they are capable of preparing to drive safely by satisfying the following requirements: • 8.1.1. Adjusting seat as necessary to obtain a correct seated position; • 8.1.2. Adjusting rear-view mirrors, seat belts and head restraints if available; • 8.1.3. Random checks on condition of tyres, steering, brakes, lights, reflectors, direction indicators and audible warning device; • 8.1.4. Checking power-assisted braking and steering systems; checking condition of wheels, wheelnuts, mudguards, windscreen, windows and wipers, fluids; checking and using instrument panel including recording equipment as defined in Regulation (EEC) No 3821/85;	This training shall be organised by **an approved training centre.** If a driver moves to another undertaking, the periodic training already undergone must be taken into account. **ARTICLE 8: CPC CERTIFYING PERIODIC TRAINING** When a driver has completed the periodic training referred to in Article 7, the Member States' competent authorities or the approved training centre shall issue him or her with a CPC certifying periodic training. The following drivers shall undergo a first course of periodic training: • holders of a CPC as referred to in Article 6, **within five years of the issue of that CPC**; • the drivers referred to in Article 4, **within five years** of the respective dates referred to in Article 14(2), in accordance with a timetable decided on by the Member States. **Member States may reduce or extend the periods of time**, so that they coincide with the date of expiry of the driving licence or so as to ensure the gradual introduction of periodic training. **The period may not, however, be shorter than three years or longer than seven years.** **A driver who has completed a first course of periodic training** as referred to in paragraph 2 shall undergo periodic training **every five years**, before the end of the period of validity of the CPC certifying periodic training.	**driving**. Periodic training shall be designed to expand on, and to revise, some of the subjects referred in section 1 of Annex I. It shall cover a variety of subjects and shall always include at least 1 road safety related subject. The training subjects shall take into account developments in the relevant legislation and technology, and shall, as far as possible, take into account the specific training needs of the driver. That training shall be organised by an approved training centre. Training shall consist of classroom teaching, practical training and, if available, training by means of information and communication technology (ICT) tools or on top-of-the-range simulators.

• 8.1.5. Checking air pressure, air tanks and suspension; • 8.1.6. Checking safety factors relating to vehicle loading; • 8.1.7. Checking the coupling mechanism and the brake and electrical connections; • 8.1.9. Reading a road map, route planning, including the use of electronic navigation systems (optional). 8.2. **<u>Special manoeuvres to be tested</u>** with a bearing on road safety: • 8.2.2. Reversing along a curve, the line of which shall be left to the discretion of the Member States; • 8.2.3. Parking safely for loading/unloading at loading ramp/platform or similar installation; 8.3. **<u>Behaviour in traffic</u>**: Applicants must perform all the following actions in normal traffic situations, in complete safety and taking all necessary precautions: • 8.3.1. Driving away; • 8.3.2. Driving on straight roads; • 8.3.3. Driving round bends; • 8.3.4. Crossroads; • 8.3.5. Changing direction; • 8.3.6. Approach/exit of motorways or similar (if available; • 8.3.7. Overtaking/passing; • 8.3.8. Special road features; • 8.3.9. Taking necessary precautions when alighting from the vehicle. **9. MARKING OF THE TEST OF <u>SKILLS AND BEHAVIOUR</u>:**	**ANNEX 1: Minimum qualification & training requirements** **SECTION 1: LIST OF SUBJECTS** The minimum level of knowledge may not be less than **<u>level 2</u> of the training-level structure** provided for in Annex I to Decision 85/368/EEC, i.e. level reached during compulsory education, supplemented by professional training. <u>1. Advanced training in rational driving based on safety regulations</u> • 1.1. To know the characteristics of the **transmission system** in order to make the best possible use of it; • 1.2. To know the technical characteristics and operation of the **safety controls** in order to control the vehicle, minimise wear and tear and prevent disfunctioning: specific features of hydraulic vacuum servobrake circuit, limits to the use of brakes and retarder, combined use of brakes and retarder, making better use of speed and gear ratio, making use of vehicle inertia, using ways of slowing down and braking on downhill stretches, action in the event of failure;	**AMENDMENTS SECTION 1** The minimum level of qualification shall be comparable at least to level 2 of European Qualifications Framework as provided for in Annex II to Recommendation of the European Parliament and of the Council of 23 April 2008. 1.2. To know technical characteristics and operation of the **safety controls** in order to control the vehicle, minimise wear and tear and prevent disfunctioning: limits to the use of brakes and retarder, combined use of brakes and retarder, making better use of speed and gear ratio, making

9.2. During their assessment, driving examiners shall pay special attention to whether an applicant is showing a **defensive and social driving behaviour**. It includes **adapted and determined (safe) driving**, taking into account road and weather conditions, taking into account other traffic, taking into account the interests of other road users (particularly more vulnerable) and **anticipation**. 9.3. The driving examiner will furthermore assess whether the applicant is: • 9.3.1. Controlling the vehicle; • 9.3.2. Driving economically and in an environmentally friendly way; • 9.3.3. Observation; • 9.3.4. Priority/giving way; • 9.3.5. Correct position on the road; • 9.3.6. Keeping distance; • 9.3.7. Speed; • 9.3.8. Traffic lights, road signs and other indications; • 9.3.9. Signalling; • 9.3.10. Braking and stopping. **II. Knowledge, skill and behaviour for driving a power-driven vehicle:** Drivers of all power-driven vehicles must at any moment have the knowledge, skills and behaviour described under points 1 to 9 (II.I), with a view to be able to: • Recognise traffic dangers and assess their seriousness; • Have sufficient command of their vehicle not to create dangerous situations and to react appropriately should such situations occur;	• 1.3. Ability to **optimise fuel consumption**: optimisation of fuel consumption by applying know-how as regards points 1.1 and 1.2.	use of vehicle inertia, using ways of slowing down and braking on downhill stretches, action in the event of failure, use of electronic and mechanical devices such as Electronic Stability Program (ESP), Advanced Emergency Braking Systems (AEBS), Anti-Lock Braking System (ABS), traction control systems (TCS) and in vehicle monitoring systems (IVMS) and other, approved for use, driver assistance or automation devices. 1.3. Ability to optimise fuel consumption: optimisation of fuel consumption by applying know-how as regards points 1.1 and 1.2: importance of anticipating traffic flow, appropriate distance to other vehicles and use of the vehicle's momentum, steady speed, smooth driving style and appropriate tyre pressure, and familiarity with intelligent transport systems that improve driving efficiency and assist in route planning. 1.3a. Ability to anticipate, assess and adapt to risks in traffic: to be aware of and adapt to different road, traffic and weather conditions, anticipate forthcoming events; to understand how to prepare and plan a journey during abnormal weather conditions; to be familiar with the use of related safety equipment and to understand when a journey has to be postponed or cancelled due to extreme weather conditions; to adapt to the risks of traffic, including dangerous behaviour in traffic or distracted driving (through the use of electronic devices, eating, drinking, etc.); to recognise and adapt to dangerous situations and to be able to cope with stress deriving therefrom, in particular related to size and weight of the vehicles and

• Comply with road traffic regulations, and in particular those intended to prevent road accidents and to maintain the flow of traffic, • Detect any major technical faults in their vehicles, in particular those posing a safety hazard, and have them remedied in an appropriate fashion; • Take account of all the factors affecting driving behaviour so as to retain full use of the faculties needed to drive safely; • Help ensure the safety of all road users, and in particular of the weakest and most exposed by showing due respect for others.	• 1.4. Ability to **load the vehicle** with due regard for safety rules & proper vehicle use: forces affecting vehicles in motion, use of gearbox ratios according to vehicle load and road profile, calculation of payload of vehicle or assembly, calculation of total volume, load distribution, consequences of overloading the axle, vehicle stability and centre of gravity, types of packaging and pallets; main categories of goods needing securing, clamping and securing techniques, use of securing straps, checking of securing devices, use of handling equipment, placing and removal of tarpaulins.	vulnerable road users, such as pedestrians, cyclists and powered two wheelers; to identify possible hazardous situations and properly interpret how these potentially hazardous situations may turn into situations where crashes can no longer be averted and selecting and implementing actions that increase the safety margins to such an extent that a crash can still be averted in case the potential hazards should occur. 1.4. Ability to load the vehicle with due regard for safety rules and proper vehicle use: forces affecting vehicles in motion, use of gearbox ratios according to vehicle load and road profile, use of automatic transmission systems, calculation of payload of vehicle or assembly, calculation of total volume, load distribution, consequences of over-loading the axle, vehicle stability and centre of gravity, types of packaging and pallets; main categories of goods needing securing, clamping and securing techniques, use of securing straps, checking of securing devices, use of handling equipment, placing and removal of tarpaulins. 2.1. To know the social environment of road transport and the rules governing it: maximum working periods specific to the transport industry; principles, application and consequences of Regulations (EC) No 561/2006 and (EU) No 165/2014 of the European Parliament and of the Council; penalties for failure to use, improper use of and tampering with the tachograph; knowledge of the social environment of road transport: rights

	2. Application of regulations • 2.1. To know the **social environment of road transport and the rules** governing it; maximum working periods specific to the transport industry; principles, application and consequences of Regulations (EEC) No 3820/85 and (EEC) No 3821/85; penalties for failure to use, improper use of and tampering with the tachograph; knowledge of the social environment of road transport: rights and duties of drivers as regards initial qualification and periodic training. • 2.2. To know the regulations governing the **carriage of goods**: transport operating licences, obligations under standard contracts for the carriage of goods, drafting of documents which form the transport contract, international transport permits, obligations under the Convention on the Contract for the International Carriage of Goods by Road, drafting of the international consignment note, crossing borders, freight forwarders, special documents accompanying goods.	and duties of drivers as regards initial qualification and periodic training 2.2. To know regulations governing the carriage of goods: transport operating licences, documents to be carried in the vehicle, bans on using certain roads, road-use fees, obligations under standard contracts for the carriage of goods, drafting of documents which form the transport contract, international transport permits, obligations under the Convention on the Contract for the International Carriage of Goods by Road, drafting of the international consignment note, crossing borders, freight forwarders, special documents accompanying goods. 3.7. Objective: to know the economic environment of road haulage and the organisation of the market: road transport in relation to other modes of transport (competition, shippers), different road transport activities (transport for hire or reward,

	3. Health, road and environmental safety, service, logistics • 3.1. To make drivers aware of the **risks of the road** and of accidents at work; • 3.2. Ability to prevent **criminality and trafficking** in illegal immigrants; • 3.3. Ability to **prevent physical risks;** • 3.4. Awareness of the importance of **physical and mental ability;** • 3.5. Ability to assess **emergency** situations; • 3.6. Ability to adopt behaviour to help **enhance the image of the company;** • 3.7. To know the **economic environment** of road haulage and organisation of the market: road transport in relation to other modes of transport (competition, shippers), different road transport activities (transport for hire or reward, own account, auxiliary transport activities), organisation of the main types of transport company and auxiliary transport activities, different transport specialisations (road tanker, controlled temperature, etc.), changes in the industry (diversification of services provided, rail-road, subcontracting, etc.). **SECTION 2: COMPULSORY INITIAL QUALIFICATION** 2.1. Combining course attendance and a test • Initial qualification must include the teaching of all **subjects in the list under section 1**. • The duration must be **280 hours.**	own account, auxiliary transport activities), organisation of the main types of transport company and auxiliary transport activities, different transport specialisations (road tanker, controlled temperature, dangerous goods, animal transport, etc.), changes in the industry (diversification of services provided, rail-road, subcontracting, etc.). **AMENDMENTS SECTION 2** Each trainee driver must drive for at least 20 hours individually in a vehicle of the category concerned which meets at least the requirements for test vehicles as set out in Directive 2006/126/EC. Member States may allow part of the training to be delivered by the approved training centre by means of ICT tools, such as e-learning, while ensuring that the high quality and the effectiveness of the training are maintained, and by selecting the subjects where ICT tools can most effectively be deployed. In particular Member States shall require reliable user identification and appropriate means of control. Member States may count specific training required under other Union legislation as part of the training. This includes, but is not restricted to, training required under Directive 2008/68/EC of the European Parliament and of the Council (*) for the transport of dangerous goods, training on disability awareness under Regulation (EU) No 181/2011 of the European Parliament and

	• Each trainee driver must drive for **at least 20 hours individually in a vehicle** of the category concerned which meets at least the requirements for test vehicles as defined in Directive 91/439/EEC. When driving individually, the **trainee driver must be accompanied by an instructor, employed by an approved training centre**. • Each driver may drive for **a maximum of eight hours of the 20 hours of individual driving on special terrain or on a top-of-the-range simulator**. • For the drivers referred to in Article 5(5) the length of the initial qualification must be 70 hours, including five hours of individual driving. • At the end of that training, Member States' competent authorities or the entity designated by them shall give the driver **a written or oral test**. The test must include **at least one question on each** of the objectives in the list of subjects of section 1.	of the Council and training on animal transport under Council Regulation (EC) No 1/2005.
	<u>2.2. A test</u> Member States' competent authorities or the entity designated by them shall organise the aforementioned theoretical and practical tests. • **Theoretical test** consists of at least 2 parts:	The vehicle used for the practical test must meet at least the requirements for test vehicles set out in Directive 2006/126/EC.

	○ **questions** including multiple-choice questions, requiring a direct answer, or combination of both; ○ **case studies**. The minimum duration must be **four hours**. • **Practical test** consists of two parts: ○ **a driving test** aimed at assessing training in rational driving based on safety regulations. The test must take place, whenever possible, on roads outside built-up areas, on fast roads and on motorways (or similar), and on all kinds of urban highways presenting the **different types of difficulties**. It would be desirable for this test to take place in **different traffic density conditions**. The min duration must be **90 minutes**; ○ **a practical test** covering at least points 1.4-1.6, 3.2-3.3, 3.5. The min duration must be **30 minutes**. ○ The vehicle used for the practical test must meet at least the requirements for test vehicles as defined in Directive 91/439/EEC. ○ Practical test may be supplemented by **a third test taking place on special terrain or on a top-of-the-range simulator**. The duration of this is not fixed. Should the driver undergo such a test, its duration may be deducted from the 90 min of the driving test, but the time deducted may not exceed 30 min. **SECTION 3: ACCELERATED INITIAL QUALIFICATION** • Accelerated initial qualification must include the teaching of **all subjects in the list in section 1**. Its duration must be **140 hours**. • Each trainee must **drive for at least 10 hours individually in a vehicle** of the category concerned which meets at least the requirements for test vehicles as defined in Directive 91/439/EEC. When driving individually, the **trainee driver must be accompanied by an instructor**, employed by an approved training centre.	**AMENDMENTS SECTION 3** Each trainee driver must drive for at least 10 hours individually in a vehicle of the category concerned which meets at least the requirements for test vehicles set out in Directive 2006/126/EC. **AMENDMENTS SECTION 4** Compulsory periodic training courses must be organised by an approved training centre. Their duration must be of 35 hours every five years, given in periods of at least seven hours, which may be split over two consecutive days. Whenever e-learning is used, the approved training centre shall ensure that the proper quality of the training is

	• Each driver may drive for **a maximum of four hours of the 10 hours of individual driving on special terrain or on a top-of-the-range simulator**. • At the end of that training, Member States' competent authorities or the entity designated by them shall give the driver **a written or oral test**. The test must include at least one question on each of the objectives in the list of subjects of section 1. **SECTION 4: COMPULSORY PERIODIC TRAINING:** • Compulsory periodic training courses must be organised by an approved training centre. Their duration must be of **35 hours every five years**, **given in periods of at least seven hours**. • Such periodic training may be provided, in part, on **top of-the-range simulators**.	maintained, including by selecting the subjects where ICT tools can most effectively be deployed. In particular, Member States shall require reliable user identification and appropriate means of control. The maximum duration of the e-learning training shall not exceed 12 hours. At least one of the training course periods shall cover a road safety related subject. The content of the training shall take into account training needs specific to the transport operations carried out by the driver and relevant legal and technological developments and should, as far as possible, take into account specific training needs of the driver. A range of different subjects should be covered over the 35 hours, including repeat training where it is shown that the driver needs specific remedial training. Member States may consider counting the completed specific training as required under other Union legislation for up to one of the stipulated seven-hour periods. That includes, but is not restricted to, training required under Directive 2008/68/EC for the transport of dangerous goods, training on animal transport under Regulation (EC) No 1/2005, and, for the carriage of passengers, training on disability awareness under Regulation (EU) No 181/2011. However, Member States may decide that completed specific training as required under Directive 2008/68/EC for the transport of dangerous goods counts as two of the seven-hour periods, provided that this is the only other training that is taken into account in the periodic training.

Annex B: Overview of survey techniques for acceptance of an interention

Several studies propose standardized survey scales to measure aspects of acceptance. One of the first survey instruments was developed by Van Der Laan et al. (1997) and focuses on the dimensions of system usefulness and satisfaction. The authors used a questionnaire consisting of nine 5-point rating scale items, with item scores from -2 to +2, as shown in Table 18.

Table 18: Nine items of the questionnaire (Van Der Laan et al., 1997)

My judgements of the (…) system are … (please tick a box on every line)							
1	Useful						Useless
2	Pleasant						Unpleasant
3	Bad						Good
4	Nice						Annoying
5	Effective						Superfluous
6	Irritating						Likeable
7	Assisting						Worthless
8	Undesirable						Desirable
9	Raising alertness						Sleep-inducing

Bangor et al. (2008) introduced the System Usability Scale (SUS) which is a widely adopted instrument to evaluate the subjective rating of users of a new system with respect to usability, effectiveness and satisfaction. It contains 10 items with a 5 point rating scale, from strongly disagree to strongly agree, as described in Table 19.

Table 19: The System Usability Scale (Bangor et al., 2008)

	System Usability Scale	Strongly disagree – Strongly agree				
		1	2	3	4	5
1	I think that I would like to use the system frequently					
2	I found the system unnecessarily complex					
3	I thought the system was easy to use					
4	I think that I would need the support of a technical person to be able to use the system					
5	I found the various functions in this system were well integrated					
6	I thought there was too much inconsistency in this system					
7	I would imagine that most people would learn to use this system very quickly					

8	I found the system very awkward to use					
9	I felt very confident using the system					
10	I needed to learn a lot of things before I could get going with this system					

Nielsen (1993) introduced the Attributes of Usability Scale consisting of 5 items, including: learnability (i.e. learning to operate the system was easy for me), efficiency (my interaction with the system was clear and understandable), memorability (it was easy to remember how to use the system), accuracy (it was easy to use the system quickly without making errors) and subjective satisfaction (the system was easy and comfortable to use). All items are scored on a seven-point Likert scale from disagree to agree, as shown in Table 20.

Table 20: Nielsen's Attributes of Usability Scale (Nielsen, 1993)

Nielsen's Attributes of Usability Scale										
			1	2	3	4	5	6	7	
1	Learnability	bad								good
2	Efficiency	bad								good
3	Memorability	bad								good
4	Errors (Accuracy)	bad								good
5	Subjective Satisfaction	bad								good

Jian et al. (2000) introduced the checklist for system trust, as shown in Table 21, i.e. survey instrument to measure trust between people and automation. It contained 12 items measured on a 7-point Likert scale (from 'not at all' =1 to 'extremely' =7). The main constructs were mistrust (the system behaves in an underhanded manner), harm (the system's actions will have a harmful or injurious outcome), suspicion (I am suspicious of the system's intent action, or outputs), confidence (I am confident in the system) and security (The system provides security).

Table 21: Checklist for trust between people and automation (Jian et al., 2000)

Checklist for trust between people and automation										
			1	2	3	4	5	6	7	
1	The system is deceptive	Not at all								extremely
2	The system behaves in an underhanded manner	Not at all								extremely
3	I am suspicious of the system's intent, actions or output	Not at all								extremely
4	I am wary of the system	Not at all								extremely
5	The system's actions will have a harmful or injurious outcome	Not at all								extremely

6	I am confident in the system	Not at all								extremely
7	The system provides security	Not at all								extremely
8	The system has integrity	Not at all								extremely
9	The system is dependable	Not at all								extremely
10	The system is reliable	Not at all								extremely
11	I can trust the system	Not at all								extremely
12	I am familiar with the system	Not at all								extremely

In Adell et al. (2014), a modified version of the UTAUT survey based on Venkatesh et al., (2003) was presented for evaluations in the context of driver assistance systems, as shown in Table 22. It deals with different aspects of the UTAUT theory including: behavioural intentions to use the system, performance expectancy, effort expectancy and social influence. All items are evaluated based on a 7-point Likert scale (from ‘strongly disagree’ to ‘strongly agree’).

Table 22: The Unified Theory of Acceptance and Use of Technology model survey (Adell et al., 2014)

Behavioural intention to use the system	
	Imagine that the system was on the market and you could get the system in your own car, how would you rate each of the following statements?
BI1	I would intend to use the system in the next 6 months
BI2	I would predict I would use the system in the next 6 months
BI3	I would plan to use the system in the next 6 months
Performance Expectancy (PE)	
PE1	I would find the system useful in my driving
PE2	Using the system enables me to react to the situation more quickly
PE3	Using the system increases my driving performance
PE4	If I use the system, I will decrease my risk of being involved in an accident
Effort Expectancy (EE)	
EE1	My interaction with the system would be clear and understandable
EE2	It would be easy for me to become skilful at using the system
EE3	I would find the system easy to use
EE4	Learning to operate the system is easy for me
Social Influence (SI)	
SI1	People who influence my behaviour would think that I should use the system
SI2	People who are important to me would think that I should use the system
SI3	Authorities would be helpful in the use of the system
SI4	In general, authorities would support the use of the system

Finally, the NASA Task Load Index (Hart, 2006; Hart and Staveland, 1998) was also an indirect multidimensional survey instrument to measure the workload that a user experienced when interacting with a system. The hypothesis was that when the user experienced a higher workload to use the system, the system might not be accepted as much compared to a system that required less effort to use. It could be considered as a measurement of the concept of 'Ease of use' of a driver assistance system. The NASA Task Load Index instrument, as shown in Table 23, consists of 6 items with a scale ranging from 'very low' to 'very high', or from 'perfect' to 'failure'.

Table 23: NASA Task Load Index (Hart and Staveland, 1988)

NASA Task Load Index	
1	How mentally demanding was the task?
2	How physically demanding was the task?
3	How hurried or rushed was the pace of the task?
4	How successful were you in accomplishing what you were asked to do?
5	How hard did you have to work to accomplish your level of performance?
6	How insecure, discouraged, irritated, stressed and annoyed were you?

Potential other items, based on literature, to include in acceptance surveys are:

- Warning understandability (Winkler et al., 2018), i.e. to what extent the warnings generated by a system were easily understood by the driver.
- Warning helpfulness (Winkler et al., 2018), i.e. to what extent the warning message was considered helpful in the experienced situation.
- Distraction potential, i.e. to what extent the warning message is experienced by the driver is causing potential distraction.
- Endorsement, i.e. the extent to which the driver would recommend the system to others (especially people that were considered as important to the driver, such as family or close friends).
- Usage and Purchase intention: i.e. the willingness to use or the willingness to pay (Adell et al., 2014), as well as the price the driver was willing to pay to have the system.

Annex C: Overview of assistance systems deployed by OEMs

The assistance systems most commonly deployed by OEM in buses and coaches are:

- Anti-lock braking systems (ABS) – The system prevents skidding, where loss of steering and control result from locked wheels in case of hash or emergency braking. These systems were some of the pioneer systems to become mandatory for EU vehicle-type approval as were found to significant decrease collision with vulnerable road users, i.e. pedestrians, cyclists and animals.
- Electronic Stability Control (ECS) – ECS is an active safety system that evolves from anti-lock braking technology use by stabilising the vehicle and prevent skidding under wider driving conditions, which can be fitted to cars, buses, coaches and trucks and takes advantage on in-wheel independent speed sensors and braking pressure control for each wheel.
- Traction control systems (TCS) – Traction Control is often a secondary function of the electronic stability control designed to prevent loss of traction of driven road wheels. TCS is activated when throttle input and engine torque are mismatched to road surface conditions. Generally, the systems usually act by adjusting the brake force applied to one or more wheels or by reducing engine torque output, e.g. by constricting fuel supply or engine throttle.
- Collision Avoidance Systems (CAS) encompass a set of distinct systems aiming to prevent vehicle collision and mitigate its severity whenever the collision is unavoidable. The most widespread of such systems are the Autonomous emergency braking (AEB) and the Forward Collision Warning (FCW), but other systems such as Adaptive and Cooperative Adaptive Cruise Control (ACC, CACC), Reverse Collision Warning Systems (RCW) and also, to some extent, Lane Assistance Systems can be regarded as CAS.
- Forward Collision Warning (FCW) systems identify, classify and monitor the distance between the vehicle and potential obstacles that can lead to a collision. These systems make use of radar, camera and/or LIDAR data to assess the risk and time to collision (TTC) and provide the driver with real-time warnings and timely alerts. The feedback provided usually is restricted to visual and audible alerts, although some systems also enable haptic feedback through the steering, braking pedal or even the driver's seat.
- Autonomous emergency braking (AEB) – Building on FCW features, AEB systems monitor the distance to vehicles or other road users and apply braking to either prevent a collision occurring or to mitigate the impact severity. Such systems can be based on different technologies or even by a combination of several technologies, being radar and camera systems the most commonly employed.
- Emergency Brake Assist (EBA) acts in emergency cases to address the problem of insufficient pressure being applied to the brake by drivers in emergency situations that leads to increased stopping distances. Such technology comes as standard on many new vehicles and forms part of an EU legislative package on pedestrian protection.
- Cruise Control, Adaptive Cruise Control (ACC) and Cooperative ACC (CACC) are systems designed to help the driver conserving the vehicle speed with potential large impact on fuel saving and traffic fluency. The classical cruise control system doses but is not capable to adjust the speed in accordance to the driving context, namely traffic,

road layout or topography. To adjust speed primitive systems solely made use of the throttle and fuel injection control, however were unable to keep the target speed in steep descending slopes. More advance systems, especially for the case of heavy duty vehicles are able to control both engine output and braking system, including secondary systems such as retarders and engine brake.

In order to overcome the incapacity of adjusting speed to the road environment, using sensors employed by AEB and FCW systems, ACC systems are able to adjust the target cruise speed whenever the headway distance to the vehicle in-front is lower that a specific threshold statically or dynamically defined as a function of current speed.

More recently CACC systems have been tested, mostly for trucks but could also be applicable to coaches or even light vehicles. In such cooperative systems, vehicles platoon to follow the vehicle in front at close range, aiming at improving fuel efficiency and traffic fluency. During platooning operations, the leading vehicle sets the platoon speed and the trailing vehicles follow its lead. The shortened gap between vehicles during platooning requires V2V communication in order to decrease the trailing vehicle reaction time to adjust to the motion of preceding vehicles.

- Lane Assistance Systems (LAS) act in order to conserve the vehicle within the lane limits. There are examples of active systems, often called Lane Keeping Systems (LKS), and passive ones commonly named Lane Departure Warning (LDW) systems. The latter ones, as the name suggests, provide the driver with audible and visual warnings whenever the vehicle is about to unintentionally veer of the lane or the road without. Steering wheel and driver's seat haptic feedback is also found, however were seldom found lead to undesirable driver actions in cases where the driver is unfamiliar with the system. In the case of active LKS, the system uses the electric-mechanical or electric-hydraulic steering pump to actively correct the vehicle trajectory, keeping it centred within the lane using smooth steering corrections.
- Reverse Collision Warning (RCW) systems warn the driver about obstacles in the rear section of the vehicle during revere manoeuvres. Common systems derive from parking assistance systems and employ short range ultrasonic sensors, whereas more advance systems make use of surround vision camera systems and/or short range radars, similar to the ones used for monitoring the vehicles' blind spot. The system feedback, audible and visual, tends to correlate the assessed risk severity, both in terms of frequency and pitch/intensity.
- Reverse and Surround/Omniview (360◦) Camera Systems – These currently widespread camera based systems make use of one or more video cameras with wide-angle lenses that assist the driver mainly during reversing and low speed manoeuvres, by alleviating or circumventing poor visibility and vehicles' blind spots.
- Blind Spot Monitoring (BSM) and camera mirrors can be part of Surround Camera systems or act independently to mitigate the risk of collision with other vehicles or vulnerable road users. Alternatively, some BSM systems employ short range (24GHz or 77GHz) radars to monitor and detect obstacles, within the vehicles' blind spot, that the driver may not be aware of.
- Emergency Stop Signals (ESS) is a system that produces specific stop signals pattern in case of an emergency brake, namely the rapid blinking stop lamps at 4 Hz. The goal of such systems is to help drivers in following vehicles to quickly recognize emergency brake and high retardation situations ahead and thereby react accordingly, reducing reaction times and adjusting braking pressure.
- Traffic Sign recognition (TSR) systems use image processing techniques to detect and identify the traffic signs. The detection methods can be generally divided into colour

based, shape based and learning based methods and enable the vehicle to recognize the traffic signs and warn the driver accordingly.

- Crosswind Stabilization Systems are relatively recent Driver Assistance features. These systems generally employ sensors to detect lateral forces acting on the vehicle and vehicle load and steering characteristics of the driver provides input for the steering and eventually suspension systems to counteract the lateral wind load in order to conserve the vehicle heading and attenuate the vehicle body rolling oscillations.
- Top Speed Limiters (TSL) are mandatory for heavy duty vehicles, as in the case of buses and coaches, and assure that these vehicles cannot exceed the maximum legal speed limits of country the country of register for the vehicle type. However, these limits are hard set by the OEM and blind to the type and speed limits of the road where the vehicle is driving.
- Intelligent speed adaptation (ISA) aim to overcome the limitation of traditional speed limiters by ensuring that vehicle speed does not exceed a safe or legally enforced speed limit, alerting the driver or even automatically adjusting the vehicle speed. These systems are designed to detect and alert a driver whenever a vehicle enters a new speed zone, or when different speed limits are in force, according to particular time of day, day of week or weather conditions. ISA implementations can make use of information that can be obtained from the vehicle position and high definition speed limit digital mapping, taking into account speed limits known for the position, by interpreting road features such as signs by means of TSR or using infrastructure message broadcast (V2I systems) such as DSRC (Direct Short-Range Communications) or radio beacons.

  ISA systems can be either passive (informative or advisory ISA), feedback-active (in the cases of supportive or warning ISA) and active (intervening or mandatory ISA). Passive systems inform the driver, usually by means of visual and auditory feedback, about the discrepancy between current vehicle and recommended or statutory local maximum speeds and advise the driver about corrective actions. Active systems actually intervene by preventing speeding by restricting throttle and fuel injection or even actively braking.

  Some systems although not adjusting automatically the vehicle speed provide active (haptic) feedback for supporting the driver to comply with local speed limits, usually by stiffening or actively countering the pressure exerted on the accelerator pedal by the driver.

  Recommendations for future mandatory systems advise these should allow the driver to override active ISA systems, in order to enhance global acceptance and ensure safety of particular manoeuvres, such as overtaking.
- Hill Hold and Descent Control (HDC) functions are typically a comfort feature for M1 category vehicles, i.e. cars, but can have a profound impact on the safety of heady duty vehicles. During positive slopes, hill hold systems activates the brake until the clutch is at the friction point, making it easier to start up hills from a stop in manual and robotized transmission vehicles. On its turn, HDC allows for a smooth and controlled negative slope mediation without the driver needing to touch the brake pedal, using the ABS to control each wheel's speed. Hill Descent Control helps drivers to optimally distribute the braking force throughout wheels and braking systems, assisting steep downslope driving in slippery conditions without overheating service breaks.
- E-call systems relay an automated message to emergency services following a road crash which includes the precise crash location in hope of reducing the consequences of injury through fast and efficient care.

The in-vehicle emergency eCall can be generated either manually by the vehicle occupants, by activating a button, or automatically via activation of in-vehicle inertial and air-bag sensors after a crash.

- Event/Journey data recorder (EDR), similarly to airplane black box recorders, are in-vehicle data recorders which can provide useful data for road safety purposes, namely crash data recorders and journey data recorders. The former loop records the vehicle data on a buffer, which can be permanently stored whenever the system detects a critical event (e.g. when a crash or traffic violation is detected). The latter continuously records data from the vehicle entire journey and can provide information regarding driving behaviour and traffic rules violations and other law infringements. In theory, these can be used to monitor driving in relation to insurance costs, driver performance analysis and training or even used for traffic management purposes. These devices, such as digital tachographs are currently mandatory for buses of category M2 and M3, as well as heavy-duty goods vehicles. Older systems only record speed and driving time, to assess speeding and compliance with working time legislation, but EU regulations 165/2014 and 502/2018 impose the use of smart tachographs from 2019 onwards. The new generation of smart tachographs include, apart from speed and driving times, the vehicle GPS location and smart DSRC modules for remote communication, the latter allowing for authorities to inspect the data and assess existing law infringements while the vehicle is in motion.
- Tire Pressure Monitoring Systems (TPMS) monitor the air pressure inside the pneumatic and report real-time tire-pressure information to the driver of the vehicle, either via pictogram displays or a simple low-pressure warning light. In some systems this information is also relayed to workshops and fleet managers. TPMS can be divided into two different types, direct (dTPMS) and indirect (iTPMS), and are provided both at OEM level or as an aftermarket solution. The goal of TPMS systems is to help avoiding traffic accidents, poor fuel economy, and increased tire wear arising from incorrectly-inflated and/or overheating tires.

  Unlike dTPMS systems, which employ pressure sensors on each wheel, either internal or external, to physically measure the tire pressure, and eventually temperature, and report it to the vehicle's instrument cluster, iTPMS systems estimate air pressure based on the wheel rotational/angular speeds and other speed sensors, such as the ones employed by ABS and ESC systems.
- Alcohol Interlock Systems are automatic control systems which are designed to prevent driving with excess alcohol by requiring the driver to blow into an in-vehicle breathalyser before starting the ignition. The alcohol interlock can be set at different levels and limits, according to the legislation of the country of register. However, unless a smart system is deployed to take into account the vehicle location and local laws, its interoperability within the EU could be hampered by the differences observed in the legal alcohol limits tolerated by the different countries' regulations.
- Intelligent Light System can manage entirely autonomously the lighting according to information collected by the vehicle luminosity sensors and in some cases on-board cameras, in order to alleviate drivers' workload in task demanding contexts. Given the elevated positioning of its lighting system, Adaptive High Beam and Led Matrix Systems are of particular interest to heavy duty vehicles. These systems are able to tailor the light cone range and shape to protect road users travelling ahead or in the opposite direction from glare whilst conserving the maximum seeing range.
- Rain Detection Systems is typically a switching device activated by a change in light reflection pattern resulting from the distinct light refraction, arising from the differing

light propagation speeds, in different mediums, namely the glass and the rainfall water. Upon detecting rainfall, the sensor can trigger the vehicle wipers and autonomously adjusts the wipers speed to rainfall intensity.

- Smart Navigation Systems combine the classical geographical information and route planning algorithms with multiple layers of high definition mapping comprising information pertaining legal speed limits, road geometry, safety hot/black spots, road landmarks, etc. that allow for vehicles to precisely define the vehicle location and thereby complement the information collected by in-vehicle senses on real-time.

Driver Monitoring systems (DMS) encompasses driver attention and fatigue monitoring systems. The former typically employs cameras and/or infrared sensors to monitor driver attentiveness, by tracking the drivers' eye movement and gaze. In some cases, the system may also monitor the use of nomadic devices, such as cell phones, or the excessive interaction with the infotainment system. Whenever the driver is not focused in the driving task and a dangerous situation is detected, the system warns the driver through visual, audible or even haptic feedback. If the vehicle is fitted with active collision avoidance systems the vehicle may apply a progressive braking force in order to lead the driver to assume control or, in extreme cases, perform an emergency brake.

Annex D: Detailed literature review of real-time interventions

D.5 Cars

D.5.1 Visual

ADAS aspects such as lane departure warning, blind-spot warning, adaptive lighting, and adaptive cruise control have been used to adjust vehicle operation and improve safety and driving with visual signals. An overview of visual ADAS was provided by Hasenjager and Wersing (2018). Katsis et al. (2008) introduced an automated approach in emotion recognition, which was based on several visual biosignals. The methodology was integrated into a wearable system which was able to estimate the emotional state of car-racing drivers by classifying features extracted from facial EMG, ECG, RR, and EDA. The system classified basic human emotional states in near real time. The emotional states addressed were high or low stress, euphoria, and disappointment. The system consisted of the following: a multisensorial wearable which was responsible for the acquisition, preprocessing, and wireless transmission of the selected biosignals, a centralized module which extracted special features from the aforementioned biosignals and estimated the subject's emotional state based on a dataset containing the extracted features along with the medical experts' annotation and the system user interface.

Adell et al. (2011) developed the SASPENCE system, an ADAS which assisted the driver to keep a safe speed according to road and traffic conditions and a safe distance to the vehicle obstacle ahead. The "safe speed and safe distance" function informed and warned the driver: when the car was too close to the vehicle in front, when a collision was likely due to a positive relative speed, when the speed was too high considering the road layout and when the car was exceeding the speed limit. The findings showed positive effects of the system in terms of fewer alarm situations, shorter alarm lengths, shorter reaction times, increased headway and better interactions with vulnerable road users at intersections. The majority of the drivers would accept an intervening system, and about 1/3 would accept an advisory system. It should be kept in mind that the results are based drivers' reactions to the system and this field trial could only give indications of the short-term effects when driving for the first time with a new driver support system.

D.5.2 Auditory

Lee and Chung (2012) proposed a method for monitoring driver safety levels using a data fusion approach based on several discrete data types: eye features, bio-signal variation, in-vehicle temperature, and vehicle speed. A Fuzzy Bayesian network was implemented to predict and analyze the driver's vigilance index. The sensory data were transmitted via Bluetooth to the smartphone device. Once the evaluation metric reached 75%, a fake call service was initiated along with an **auditory** loud ringtone and maximum vibration strength to alert the driver of his current dangerous driving state. Moreover, the application provided several configurable options for the driver. For example: the user could choose which features were used in the evaluation. The average rates of true awake state predictions and true drowsy state predictions were 96% and 97%, respectively. However, a higher complexity yielded a higher accuracy of the inference network might slow down the overall processing of the smartphone device.

Similarly, Raviteja and Shanmughasundaram (2019) proposed a partial autonomous system in order to avoid collisions by giving acoustic warning signals. In that system consisting of lane detection and tracking, Lane Departure Warning (LDWS) and Blind Spot Detection and Warning System (BDWS). An acoustic warning in advance if there was lane departure or blind spot detection. Wong et al. (2019) investigated how effective are voice commands in influencing people’s speed on a semi-autonomous vehicle regardless of how occupied the driver is with secondary task, e.g. playing a mobile game. They conducted a simulator study with 20 participants. Drivers were first given a warning at the approach of one of driving scenarios, such as roundabouts, lane changes or T-junctions. This was then followed by one of three different execution commands (indicate left/right, braking, slow down), which varied both in tone and phrasing. Assertive and non-assertive voice commands were given in an identical set of driving videos separately. The results showed that participants responded quicker to assertive voice commands despite how immersive the secondary task was.

“Niggardly solutions” used driving pattern monitoring and provided **voice** alerts and warnings to users. What's more, drivers received **voice** prompts for non-eco-driving behavior and a support system provided static feedback to improve drivers’ eco-driving behavior (Zhao et al., 2015). The results indicated that the developed eco-driving support system was a cost-effective training tool to improve drivers’ eco-driving behavior in reducing emissions and fuel consumption and it was easily and friendly to drivers to apply without complicated installation. 'CarChip Fleet Pro' plugged directly into the OBD diagnostic port under the dashboard of any fleet vehicle where it continuously collected and stored vehicle trip and engine data to provide a detailed history of driver performance and vehicle operation, mainly in individual consumers (Staff et al., 2007). The logged data included trip start and end times, vehicle speeds, rates of acceleration and braking, engine performance data and detailed accident or risky data for all sudden stops, as well as an adjustable audible alarm that could be used to alert drivers of unsafe driving, whenever they exceeded speed, acceleration, or deceleration limits (Carchip, 1996). Furthermore, the Drivewise application provided personalized driving feedback in order to create a safer driver, who could save money for his everyday safe driving. It could even help young drivers develop good driving habits to help keep them safe on the road (Arumugam and Bhargavi, 2019). If any of the abnormal driving behavior was identified, a live voice alert was sent to the users immediately.

D.5.3 Haptic

Balters et al. (2018) demonstrated, through an in-lab simulator study, the feasibility of using haptic guidance to increase breathing rate, intensity, and heart rate as well as subjective perceptions of alertness and focus. A link was observed between fast breathing and speeding in a few cases, once leading to an accident. The intervention was appropriate when drivers were feeling drowsy, in order to increase alertness, energy, and focus. Fast breathing required attention resources, which could distract from driving. Yanko et al. (2000) proposed an apparatus and method for maintaining the awareness of a vehicle’s driver which comprised an accelerator pedal and activating means for actuating the vehicle’s warning system, the design of which is fulfilled in such a way, that the drivers normally operated, accelerator pedal by means of their foot at a predetermined position on it, which guaranteed their awareness. As soon, as they started to lose awareness, the given position of their foot changed involuntarily, which engaged the warning system. It was a reliable, relatively simple and inexpensive system which reacted to the driver's inattentiveness instantly and it could be easily installed on new vehicles.

D.5.4 Combinations

Apart from using a single type of feedback, studies have also evaluated combination of feedbacks for real-time interventions. First of all, Al-Taee et al. (2007) developed a smart locator and remoted diagnostic data monitoring system called On-Board Smart Box (OBSD), which provided visual and vocal alerts, information about the driving performance and vehicle status. These outputs were displayed locally on the OBSB screen via an appropriate Graphical User Interface (GUI) as well as remotely on the screen of the remote server. The OBSD system offered a highly reliable and accurate supervision from inside the vehicle and could effectively minimize the over-speed violations which were categorized as one of the major causes of accidents. Moreover, Van der Heiden et al. (2018) investigated how quickly drivers respond to a visual in-car warning using a driving simulator. The driving task was combined with an auditory task that provided different levels of cognitive distraction. The results showed that the initial reaction time to in-car warnings was significantly larger for drivers that were distracted by the auditory task. Moreover, it was proved that in-car warnings might be helpful as a last resort to prevent a crash; however, such warnings should be given timely.

Additionally, Aidman et al. (2015) examined the effects of real-time blink-velocity-derived drowsiness feedback on driver performance and levels of alertness in a military setting. A sample of 15 Army Reserve personnel volunteered to being monitored by an infrared oculography-based Optalert Alertness Monitoring System (OAMS) while they performed their regular driving tasks. A monochrome LCD screen attached to the dashboard indicator also produced auditory and visual warnings when there was found a medium or high risk range. The effect of OAMS feedback on both drowsiness and driving performance ratings was robust and statistically significant. The provision of both visual and auditory real-time feedback resulted in reduced drowsiness and improved alertness and driving performance ratings. Furthermore, in Lee and Jan (2010) visual and auditory information provided from the pre-warning system was successful in decelerating the vehicle speed in order to avoid accidents or mitigate their effects. During the vehicle movements the system continuously recorded the vehicle's moving status and conditions so that the record provided the decision basis in the accident investigation if it unfortunately happened the fatal accident.

On the same principle, Zhao and Wu (2013) conducted a driving simulator study to assess and compare the effectiveness and acceptance of an Intelligent Speeding Prediction System (ISPS) and the Intelligent Speed Adaptation (ISA). System type served as a between-subjects variable with four levels: no speed assistance system, pre-warning system developed based on the ISPS, post-warning system ISA, and combined pre-warning and ISA system. If a driver was going to speed, the ISPS presented visual and auditory warning messages via an in-vehicle human machine interface to prevent speeding. The results indicated that both pre-warning and combined systems led to greater minimum time-to-collision. The combined system resulted in slower driving speed, fewer speeding exceedances, shorter speeding duration, and smaller speeding magnitude.

Rios-Torres and Malikopoulos (2016) claimed that Collision Warning Systems (CWSs) provided warning signals and alerts to driver when potential collisions were detected through radar, acoustic and vision sensors, laser and camera. These technologies yielded relative information about the vehicle and moving or stationary obstacles. This information was then processed to determine the likelihood of a collision and to estimate the time to collision. A warning was issued if the estimated time to collision was smaller than the specific threshold under the specific scenario. Moreover, a real-time mitigation system was designed to direct driver's attention to the road with visual and auditory alerts when visual or cognitive distraction was detected (Roberts et al., 2012). Visual alerts were displayed on the windshield to the left, right, and in the center of the driver's field of view using three white LED lights. Results indicated that such a system was more obtrusive and less easy to use.

An alternative Radio Frequency Identification(RFID)-based Driver's Smart Advisory System (DSAS) was developed by Li et al. (2017), which provided drivers with a visual or an auditory warning message when they were approaching an unsignalized intersection. The authors conducted a pilot field test with the DSAS alarm on an approach towards a STOP sign intersection in a residential area. Results showed that the DSAS alarm was able to induce drivers to drive significantly slower to approach a STOP sign intersection, perform smaller fluctuation in acceleration/deceleration rates, and be more aware of a coming STOP sign indicated by decelerating earlier. Most of participants believed that auditory warning alarm was better than visual warning for a safety concern, and all of them believed that the DSAS did not cause any confusion or stress to them and provided clear warnings and guidance, so it was worthy to place it in their vehicles. DriveGain, an eco-driving smartphone application gave visual and auditory feedback on driving performance and provided interventions on acceleration, braking and speed, measured by the GPS sensor (Tulusan et al., 2012). In addition, it had a recommended gear feature which prompted the driver when to shift gears up or down. The findings revealed that DriveGain application was a cost effective way to modify drivers' behavior positively providing real-time feedback during driving.

Braun et al. (2019) researched a system which would help drivers to improve their emotional state. They proposed a driver model consisting of a set of long-term traits, like personality or expertise, and short-term traits like emotions, physiology, or cognitive load. Different interaction approaches were compared for an affective automotive interface, such as ambient light, visual notification, voice assistant, and empathic assistant. The results indicated that an emotional voice assistant with the ability to empathize with the user was the most promising approach as it improved negative states best and was rated most positively. On the other side, visual strategy was the most criticized instance, as some participants found it as disturbing or stressful. In order to reduce traffic accidents due to driver distraction, a monitoring system was developed by Dehzangi et al. (2018) using physiological, behavioral and vehicle signals. Motion signal such as accelerometer and gyroscope, ECG, GSR and CAN-Bus signal were collected during the on-road driving session. Features from each signal was evaluated independently to identify driver distraction. To improve the recognition accuracy the multimodal feature space was fused and evaluated and an average accuracy of 99.85% was obtained. As a result, the proposed multimodal system shown capability for efficient on-line driver distraction detection during naturalistic driving conditions.

D.6 Trucks

D.6.5 Visual

Commercial applications for truck drivers usually employ visual alerts. Netradyne, a technology company, has developed a camera feed-based artificial intelligence platform (i.e. “Driveri”) with an intention to reform commercial vehicle driver recognition and fleet safety. “Driveri” is a vision-based safety platform which provides fleet managers with a comprehensive view of drivers' activity through a blend of real-time driving notifications and insights with a multiple-angle, high-definition video-stream (Aaron Huff, 2019). In-cab **v**isual alerts and reminders enable truck drivers to adjust their dangerous behaviour, before a risky event occurred, through an immediate correction (Stephen et al., 2017). “Driveri” provides interventions every minute of every driving day to visually recognize and analyze driving events, enabling fleets to not just measure violations, but overall compliance. Driveri has mainly been used by the commercial vehicle sector due to the device's expensive cost. Moreover, a visual warning was issued in Bell et al., (2017). Using an IVMS vendor, a small “box-like” device emits green light indicating safe driving and yellow or red lights notifications when a risky manoeuvre was executed and there were no sound associated with the lights. The feedback was found to reduce significantly risky driving behaviour among truck drivers. Furthermore, IVMS was considered to be a fairly low-cost intervention in comparison to other safety technologies.

“Nauto Prevent” is an intelligent driver safety monitoring system which provides in-cabin visual alerts to coach commercial drivers in real-time, prevents collisions before they happened and prompts truck drivers to return their attention to the road, if a distraction is detected (Akerkar, 2018). Nauto Prevent monitors driver’s head, eyes and torso to determine if eyes are on the road. The system ensured that these alerts were issued correctly, improved driver performance and prevented further risky behavior or possible collision. Specifically, 54% fewer distractions per hour occurred from early adoption customers, a percentage reaching 70% in some drivers. Nauto Prevent is an important proactive solution and provides the context needed for real-time effective coaching. Similarly, the “SmartDrive SR4” vision-based safety platform has indicator lights that could be used to visually alert drivers to risky behaviours. SmartDrive gives drivers feedback using green, yellow and red-light notifications on the camera, depending on the severity or their risky driving performance (Aaron Huff, 2018a).

D.6.6 Auditory

The “Mentor” app gives an audible alert to drivers when they exceed a maximum speed setting (eDriving, 2017). Additionally, the Mentor app uses smartphone sensors to collect and analyze driver behaviors most predictive of risk, including phone distraction. Mentor runs on smartphones or tablets and tracks driver behaviors for acceleration, braking, speeding as well as distraction in cases where drivers pick up their phones while driving.

D.6.7 Combinations

Visual and auditory alerts are the most common applications utilized from truck drivers. For instance, in Ahmed et al. (2019), truck drivers were provided with audible alerts and visual yellow or red warning information on Forward Collision Warnings (FCWs), Distress Notifications (DNs), and Traveller Information Messages (TIMs). Truck drivers had to check that visual and auditory warning volume was loud enough to overcome masking sounds from road noise, the cab environment, or other equipment. These technologies were found to be well accepted by truck drivers and readily implementable for state-wide training of commercial drivers. Similarly, the “FleetCam” driver monitoring system is a comprehensive collision prevention system that uses cameras, sensors and artificial intelligence to detect truck driver’s eye movement, helps to prevent crashes and improves bad driving habits immediately with auditory and visual real-time feedback (FleetCam, 2019). This combination of feedback alerts from the in-cab device wakes up drivers falling asleep or discourages drivers from texting while driving. Short video clips are automatically saved from all camera angles when unwanted driver behavior was detected. The FleetCam in-cab notifications also let drivers know when they were following a vehicle too closely, accelerating too quickly or braking too harshly. Moreover, FleetCam helps customers ensure that their fleets are secure and transparent, increases driver satisfaction and improved driver reliability and safety. Drivers are less likely to engage in risky or undesirable behavior while out on the road if they know they are being monitored by cameras.

“Bendix Wingman Fusion” system uses multiple and different technology sensors and provides important audible and visual alerts to the driver in order to focus attention on the most potentially threatening situation (Aaron Huff, 2018a). Bendix offers a web portal that provides truck operators with videos of severe events along with immediate feedback on fleet and driver performance. It combines radar and camera inputs to warn drivers of collision risks. The system wirelessly transmits real-time video data and event-based information for analysis by fleet safety personnel. Moreover, in Fitzharris et al. (2017) auditory or haptic warnings were provided to truck drivers, with regards to fatigue, distractive or drowsy events. The Driver Monitoring System (DMS) fitted within the cabin of vehicles comprised of a camera using a Video Graphics Array (VGA) resolution 60- Hz global shutter image sensor and a pair of pulsed 850-nm infrared. It was found that direct feedback to the drivers' employer resulted in an additional 28.2% benefit. Furthermore, in cab warnings resulted in a 66% reduction in fatigue events, with a 95% reduction achieved by the real-time provision of direct feedback. As a result, fewer fatigue events were likely a reflection of the device itself.

D.7 Buses

D.7.8 Visual

OMNIPlus ON

In addition to FLEETBOARD, Daimler launched in 2019 a new telematics and fleet management service. Unlike FLEETBOARD that was originally developed for trucks and later on extended and adapted for buses, the new OMNIPlus ON was designed exclusively for buses. Regarding driving performance analysis, most metrics and KPIs are shared with FLEETBOARD system, however comfort KPIs are also taken into account to address a key concern of bus drivers that was one of the primary complaints raised by bus drivers about FLEETBOARD driver performance evaluation methodology.

OMNIPlus ON monitor essentially congregates the vehicle fleet and driver pool monitoring and management and performance analysis (both from vehicle and driver perspective) functionalities previously made available in FLEETBOARD. The interface with the driver is done through the OMNIPlus ON drive service that provides a two-way communication channel with the Fleet and Operations manager, document management and exchange, vehicle and damage report, navigation and route planning as well as driving performance. Additional features such as remote lighting and climate control are also available for some Daimler buses.

With the new OMNIPlus ON service, Daimler also introduces a digital signal sore (ON Signal Store) that makes available historic and real-time telematics data (up to 500 individual telematics signals) and diagnosis data in raw format.

D.7.9 Auditory

Fleetistics

Fleetistics provide a modular platform for fleet management, including telematics and dash-cam integration using GEOTAB GO CAN bus data and gateway features and GEOTAB platform for reporting. A simplistic real-time driver feedback can be tailored using GEOTAB GO acoustic alerts.

D.7.10 Combinations

ZF OPENMATICS

Operators of large vehicle fleets have to operate at maximum efficiency and safety while reducing the fuel consumption and maintenance costs of their vehicles. ZF OPENMATICS solution provides real-time data accessible through a web based platform and dedicated apps, allowing for efficient fleet management and detailed analysis of vehicle and drivers' performance.

The data can be reviewed through a summarized high-level dashboard with customizable KPIs or trip-wise for detailed driving efficiency, comfort and safety statistics. The system core is typically the Bach on-board unit, which provides a comprehensive set of vehicle-specific data, coupled with GPS, altimeter, 3D compass, gyroscope and accelerometer. The hardware has 4 dedicated CAN inputs, 2 K lines and one J1708 interface. Alternatively, ZF OPENMATICS can rely on ZF's VCU PRO on-board unit, with enhanced wireless and cellular connectivity as well as 4 additional analog input and digital output ports that can be used to further extend the systems analytic capabilities and real time in-vehicle feedback.The standard Driver feedback unit is a simple device with visual and acoustic alerts that warn driver about censurable driving behaviour, concerning efficiency and safety parameters, namely: engine overspeed, excessive vehicles speed, idling and harsh braking and accelerations.

ZF telematics solution also makes use of the company knowledge while Tier 1 solutions provider for bus in order to monitor the vehicle health in real time and perform remote diagnosis by reading DTC codes from vehicles regardless of their OEM, thus maximizing vehicles uptime for mixed fleets. ZF telematics solution can be tailored and enhanced by fleets and third-parties using its open SDK and API. Finally, the ZF OPENMATICS connectivity link can work as service aggregator, enabling multimedia streaming and on-board internet access.

WEBFLEET OptiDrive 360

WEBFLEET is one of the key players in fleet management and telematics solutions. Initially rolled out by TomTom, the business unit was later on acquired by Bridgestone. It offers tailored solutions for cars and heavy duty vehicles, particularly for buses and coaches, which specifically designed to improve driving behaviours, thus saving costs whilst improving costumer experience. WEBFLEET can be integrated into a bus company's systems to critically assess fuel efficiency and fleet and driver compliance, help navigate buses through challenging road conditions and encourage safer driving practices.

The system provides real-time data on specific behaviours such as speeding, hard braking, hard acceleration, hard turning and idling and warn drivers via instant alerts, when they engage in unsafe or inefficient driving behaviours. A key feature of WEBFLEET is its ability to provide predictive tips to the driver in real-time, e.g. when to change gear, reduce acceleration or check their optimum speed based on big data, as well as establishing a to-way communication channel with operations and fleet management. WEBFLEET's OptiDrive 360 combined with the PRO Driver Terminal offers real-time active driver feedback and advice on driving behaviour, coaching the driver to make adjustments while driving. This "training on-job" approach combined with fleet manager feedback is key to identify where drivers can improve their performance and paramount to deploy tailored training programs that enhance passenger safety and the fleet environmental performance.

OptiDrive 360 actively provides real-time insight and feedback concerning 8 key performance indicators, namely speeding, idling, real-time fuel consumption, speed fluctuations, coasting, gear shift and engine regime, harsh steering, braking or acceleration and recommended eco efficient speed profiles. Another key feature of WEBFLEET lays in its bus and trucks dedicated navigation maps and algorithms, that conveniently takes advantage of TomTom's core expertise. Using telematics heavy duty vehicle maps, routes are selected based on vehicle size, weight and speed ensuring a bus doesn't end up taking an inappropriate route. The PRO Driver Terminal offers dedicated large vehicle navigation to avoid trouble spots and reduce the chance of accidents, sharing points of interest like coach parking spaces and drop-off points.

The system is based on 3 core components: the Link on-board unit, the driver feedback unit and the web portal. For buses, both Link 510 and 710 units can be used, both offering connection to the vehicles FMS and tachograph. Since the units provide a connection with the tachograph, WEBFLEET is also able to evaluate compliance of driving time legislation and enforced speed limits and remotely download tachograph data. The Link 710 units has multiple CAN channels and provide multiple analog and digital input and output ports that can be used for 3rd party integration. Also for the driver feedback unit WEBFLEET makes several options available, from a 5'' basic navigation device with telematics integration up to a 7'' tablet Pro Driver Terminal, with integrated camera, customizable interface and NFC/RFID antennas useful paperwork and asset tracking and management. All devices connect with the Link units via Bluetooth and support WEBFLEET's OptiDrive 360.

A new trend in fleet management systems is the integration of 3rd party apps that take advantage of the core telematics hardware. Through WEBFLEET's App Centre it is possible to add new feature to the base systems, ranging from scheduling and Planning apps to Asset Management, Billing and Invoicing, CRM/ERP, route optimization, detailed reporting, maintenance management or even more advance driver performance analytics.

Some interesting apps that could be relevant to assess driver behaviour and performance are:

- Eyescan200 Forward Facing Camera, a camera link that records vehicle footage and store events with location and time tags. The system integrates into the WEBFLEET Link device via digital I/O port and records alerts whenever a G-sensor is triggered.
- VisionTrack Video solution, similarly to Eyescan uses a camera connected to the link Unit to record and upload video evidence of events though WEBFLEET's platform.
- Videmus Videomatics combines high quality video with the context of dashboard driving data and telematics. Featuring complete WEBFLEET integration the solution allows to store video evidence for a period of 4 weeks for training and performance analysis or litigation.
- FLOOME Telematics introduces an alcohol monitoring solution developed for professional drivers. According to its manufacturer it allows real-time monitoring of the blood alcohol concentration. The breathalyser is fully integrated in the WEBFLEET platform through the Link I/O ports.

Another interesting WEBFLEET's feature is the possibility to integrate with both the company ERP and custom 3rd party solutions (e.g passenger count, remote diagnosis, TPMS, etc.), using its open API and SDK: WEBFLEET.connect, LINK.connect, PRO.connect.

FLEETBOARD

FLEETBOARD is one of Daimler telematics and fleet management tools designed for buses and coaches. FLEETBOARD is a modular product range with modules dedicated to efficient driving, fleet management, driver worktime monitoring and remote tachograph download and maintenance management. Although conceived for Daimler OEM vehicles, the system is flexible and can be fitted into other OEM buses through FMS and can be retrofitted as an aftermarket solution.

FLEETBOARD drive real-time feedback is managed by FLEETBOARD DispoPilot.guide, although several high end Daimler coach and truck models also provide real-time efficient driving feedback and coaching tips using the vehicle dashboard panel or Truck Data Centre. As drivers tend to use various devices in the vehicle to retrieve information (navigation, text messages, order data, apps., etc.) drivers' workload can easily escalate into unmanageable loads that compromise safety and lead to critical message being overlooked. The FLEETBOARD DispoPilot.guide is a mobile device fully tailored to drivers' needs and combines navigation, order management, communication and apps in one device, ensuring real-time feedback and improved productivity at lower costs.

MiX TELEMATICS Fleet Manager

MiX Fleet Manager offers fleet operators access to real-time and historic information about their vehicles and drivers, with a host of features, tools and reports. The solution comprises an on-board computer, which collects and transmits valuable vehicle and driver data that is accessible through a web portal or via a mobile app. The main goals of MiX TELEMATICS solutions are to improve fuel efficiency, enhance safety and vehicle uptime and promote a safe and responsible driving behaviour.

MiX Fleet Manager is compatible with a flexible range of services, add-ons and accessories by MiX Telematics. Depending on specific operational goals video recording systems, in-cab navigation and messaging devices, driver engagement tools can be also deployed. Similarly, to many telematics and fleet management tools, MiX offers a modular and 'tailored' solution for different fleets and industry needs.

MiX Vision captures live footage using in-vehicle (both in-cab and forward-facing) and optional external cameras. The solution continuously captures rolling 72 hours of video for retrieval for an accurate view of what occurs before incidents to add context where it's needed most. MiX Vision captures footage of what happened before, during and after a crash or other triggered event and helps you establish if the driver's behaviour contributed to a collision. The two optional, external cameras offered by the MiX Vision solution can be affixed in a variety of positions to monitor activity at the back or sides of a vehicle, around an attached trailer or a fuel tank. MiX Vision is ideal for monitoring and manage their crash risk, distribution patterns, health and safety, and driver training results. Eyes on the road help to positively modify driver behaviour, encourage drivers to take responsibility for their actions and assist with accident reconstruction for analysis.

Originally, MiX Telematics real-time feedback was pushed by a device with a simple 3 colour 9 levels led display, with 3 levels for each colour. Driver trip (weighted) evaluation was displayed by means of constant colour feedback, whereas detected eco and safety critical events where communicated to the driver by audible and flashing led feedback, whose colour scheme was proportional to the incident severity. It later evolved into a led and acoustic RIBAS feedback device similar to Volvo's i-Coaching. Presently, real-time feedback and interaction between the driver and the system can also be assured by the MiX Rovi II, a rugged in-vehicle

7'' display. By connecting to one of MiX Telematics's on-board computers, MiX Rovi II provides information to the driver on-board navigation, jobs and messaging, and real-time job dispatching and driving alerts.

Drivers receive on-screen pop-ups and voice prompts when a driving violation or warning occurs, such as over-speeding in geofenced zones or driving over the road speed limit, enhancing fuel usage, reducing wear and tear on vehicles and mitigate fatigue-related incidents. The service and hardware bundle provided by MiX TELEMATICS solutions allows a thorough fleet management, by tracking vehicles and drivers in real-time, and assign jobs accordingly, identifying, monitoring and managing poor driver behaviour through targeted driver training with market proven results in wear and tear reductions and improved fuel and energy efficiency and a reduced environmental footprint.

The logical way to prevent poor driver behaviour from negatively impacting the fleet's safety is to make drivers more aware of how they drive. Poor driver behaviour, such as harsh braking and acceleration, speeding and excessive idling, can all be easily managed and corrected using MiX TELEMATICS fleet management solution. The on-board computer track incidents that increase the likelihood of an accident, and generate reports for analysis and preventative action.

Volvo Bus Telematics

Volvo Bus Telematics system has been around for nearly 20 years. Over time it has been continuously developing addressing the needs of the bus industry. The basis of the Volvo Bus Telematics system are buses able to remotely communicate with traffic control centres, fleet managers and workshops. It features a computer unit, a GPS transmitter and a cellular network communication module that can be installed in buses at assembly lines, during manufacturing, or retrofitted in all modern buses, including competing OEMs.

Volvo Bus Telematics system comprises three independent modules, which address bus operators need for information concerning both the vehicle functioning and driving methods. Since bus transit is an energy intensive business, even a small fuel efficiency can entail major savings. Volvo's system provides operators with detailed reports and precise information related to fuel consumption per bus and driver, the number of hours the bus has been in operation, the average speed, the number of stops, load and much more. Since the driver's driving style has major impact on fuel consumption and on the comfort and safety of passengers, it is possible to receive specific reports about the drivers.

A key aspect of Volvo's system designed for buses is the i-Coaching device. This device easily visible while driving acts as the driver's display and provides instant feedback, both visual and auditory, when one or more of the six parameters are exceeded, namely excessive engine speed, idling, harsh braking and acceleration, excessive speed and harsh cornering. Alike Volvo's fleet management tools, i-Coaching can be either factory-installed on Volvo buses or coaches or retrofitted on any suitable vehicle of competing OEM, as long as a basic Fleet Management service is subscribed.

IVECO BUS FLEET MANAGEMENT (FleetVisor)

A profitable fleet operation is one of the major points of attention for all bus operators and IVECO BUS telematics solution provides the tools to achieve optimal fleet management through real-time monitoring of vehicle data, evaluating each vehicle data sets and coach, monitor and score the drivers' behaviour. The Telematics box is completely integrated with the vehicles electronic architecture, capturing and analysing both vehicle and driver data at the same time.

IVECO BUS FLEET MANAGEMENT can be coupled with DriverLinc tablet/display. Apart from enabling a structured communication flow between Driver and Back Office DriverLinc adds tools to improve fuel efficiency, like Driver Coach, which supports the driver by providing feedback to improve his performance in real time. The "Driver Coach" function helps to reduce fuel consumption, providing advice on how to save fuel by comparing performance with assigned objectives and by suppling real-time feedback based on a set of 13 different driving style indicators. Along with its telematics and driving coach solution IVECO also offers some other ADAS as aftermarket solutions. In particular, reversing, frontal and side ultra wide angle cameras can be installed independently or as a kit to provide reverse assistance, blind spot monitoring or full 360-degree vision that is presented to the driver by DriverLinc display**.**

MAN Telematics and RIO

MAN Fleet Management comprises MAN|Ecostyle, MAN|Track and MAN|Check modules and provides bus operators with a simple to use and easy approach to managing their fleet efficiently and effectively. As the name denounces, the Ecostyle module provides information about how safely and economically your fleet is being driven, rating performance using an A-G grade/bands, where Track and Check modules manage location information and monitor vehicle health status and remote diagnosis, respectively. The Ecostyle module offers a driving style analysis by combining fuel efficiency data, idling, contextual speeding, over-revving and harsh braking and excessive acceleration events. As an option MAN system could include:

- The Safety Module, with optional cameras and an Incident Data Recorder, for evidence based accident analysis. By monitoring the speed, direction, accelerator position, braking, ABS status, gears, cruise control and clutch; a complete overview of what happened immediately before and after an incident happened becomes available.
- Real-time feedback, through the Driver Feedback Module, of contextual speeding, harsh braking and cornering and rollover alert can also mitigate potentially dangerous driving behaviour as it unfolds and before anything has even occurred.
- Driver Performance Management Mobile App gives drivers a detailed view of their performance against a number of criteria, and provides advice and tips to achieve improvements, detailed information on their driving performance, as well as providing analysis around particular aspects of their driving where improvements may be required. Drivers can also view league tables for their groups, giving them insight into their performance against their peers, incentivising and rewarding top performers, whilst identifying any drivers that may require tailored training programs and coaching.

Around the same time, MAN acquired Scania, it also invested into a partnership with a new digital ecosystem, RIO, focused exclusively in providing services and application for optimal logistical and fleet management. Since the summer of 2017, all Euro 6c MAN heavy duty vehicles have been fitted with the new on-board telematics module, the RIO Box, as standard. Around the same time, MAN Telematics gave place to MAN Digital Services, broadening the scope of vehicle management platform. A service of particular interest is the MAN CONNECTED CODRIVER, which offers the driver on-job training and coaching. During its normal driving operation, a specialized trainer with access to real time data remotely interacts with the driver, providing real-time instruction and coaching, whilst simultaneously performs a performance assessment. On the open, manufacturer-independent and cloud-based RIO platform, all digital and vehicle-specific services from MAN DigitalServices, logistics services from RIO and other services from additional providers are accessible.

GreenRoad BUS Telematics

GreenRoad BUS Telematics has been successfully deployed in large scale fleet across several continents. The system lays on a couple of central cornerstones: engaging in-vehicle driver coaching and deep contextual safety insights and driver status monitoring. GreenRoad states that the theory underlying their system relies more on behavioural economics than engineering, according to which driving is a learned and habitual behaviour. Hence, real-time feedback and alerts relating to unconscious errors compels drivers to make corrections. Over the course of several days, the conscious corrections become subconscious corrections.

GreenRoad's bus tracking telematics provides bus and coach drivers the real-time feedback they need to drive safer and more smoothly. The tool offers powerful bus tracking tools and dashboards highlight problematic routes and behaviours before serious issues arise. Real-time, in-the-moment feedback warns coach drivers of unsafe manoeuvers. By combining powerful and comprehensive analysis and KPIs with real-time feedback, GreenRoad bus and coach tracking telematics improve fleet utilization and operational efficiencies, enhancing asset reliability and reducing wear and tear, keeping track of service times, and monitoring health. Video telematics or map-based evidence are also available for individualised training programs and to refutes false liability claims.

A small unit the size of a matchbox, connected to a small on-board computer that measures five types of driving behaviour, namely hard braking, acceleration, land handling, cornering, and speeding, is installed on the dash to the left of the steering wheel. It has three lights: green, yellow, and red that provide continuous feedback to the driver about their driving style and unsafe or inefficient behaviours. the information sent to the dashboard unit is also recorded in cloud servers, where it can be seen by managers at headquarters and later by drivers through apps. Similarly, to its competitors, the system has been evolving into a modular system with 4 axes: i) Driver Safety, ii) Operational Efficiency, iii) Compliance and iv) Performance consulting.

Operational safety comprises traditional geolocation and tracking and performance analysis services with real-time event alerts, fuel safety and idling hotspots, and vehicle health diagnosis and fault codes. Compliance features help fleet document management and expense tracking and management. Driver safety suite include many interesting real-time feedback and driver assistance features, namely:

- In vehicle feedback, that analyses and correct more than 150 manoeuvre and compound events grouped into 5 categories (acceleration, braking, lane handling, cornering and speeding). An in-cab display gives fleet drivers objective, real-time feedback whenever a risky driving event occurs. Simple auditory and visual feedback helps fleet drivers quickly self-correct without being distracted from the road. And at the end of every trip, an automatic summary displays the trip safety level and other stats. Interactive, instant real-time and post-trip driving tips made available directly from the driver safety dashboard help drivers improve their performance, though coaching over 150 dangerous and unsafe driving patterns.
- In-Vehicle video system captures footage of events that trigger safety warnings to give you deep insight into the root cause of risky driving behaviours. It helps fleet drivers and fleet managers uncover causes motivating unsafe driving events and provide

evidence from critical seconds directly before, during, and after safety events. By doing so it is possible to evaluate external road factors with driving behaviours to understand what is driver-correctable. Always-on recording allows organizations to retrieve any portion of a driver's trip when necessary, but the system highlights and stores critical events caused by unsafe driving behaviour, so that fleet managers don't have to waste time sifting through irrelevant video footage.

GreenRoad also provides open API and SDK for third-parties to develop their tailored products, taking advantage of GreenRoad proprietary vehicle sensing and safety algorithms and road awareness and driver related deep learning analytics.

Trimble

Trimble offers one of the most comprehensive and modular telematics solutions in the market regarding driver safety and fleet management. Trimble solution provides real-time alerts concerning speeding, idle time, distance driven and other key vehicle data, providing real-time and historic reporting on fuel efficiency, GEG emission and vehicle fault codes. Trimble US and Worldwide offerings have clear differences. In the US there are currently 3 packages for you to choose from, Express, Standard and Professional, where the latter provides comprehensive driver safety and performance scorecards and consoles, as well as Trimble's FieldMaster Mobile applications.

For buses, coaches and HD vehicles in general, Trimble telematics is supported by its in-vehicle gateways, TVG 660, TVG 670 and TV G850, that are compatible with SAE J1708, 1850 PWM and 1939 protocols, as well as ISO 14230 and 15765 (OBD II CAN bus). TVG850 is specially designed for heavy duty vehicles and connect to the vehicle FMS interface. Additionally, the on-board units are fitted with GPS receiver and 3-axis IMU, to monitor driving style and harsh acceleration, braking and cornering, and two digital input ports that can be used to integrate external sensors.

Real-time driver intervention and feedback is critical to enhance driving safety behaviours and maintain long lasting driver engagement. To achieve these goals Trimble provides several Driver Interfaces, from is simple TDI 100 to ruggedized table interfaces such as the TDI 600. The TDI 100 is equipped with a series of three coloured LED indicators to indicate the driver's safety trend as they operate the vehicle. Audible alerts (optional) provides real-time feedback when harsh or unsafe manoeuvres are detected by the system. On its turn TDI 600 provides a dedicated, tamper-proof and ruggedized device tablet that builds up on the TDI 100 functionality by ensures full compliance hours of service and driver vehicle inspection reporting and access to external sensors, e.g. existing DVR and camera solutions. Additionally, Trimble Field Service Management Connect (FSM Connect) provide a suite of web services and integration tools that allow the seamless data integration with fleets ERP and CRM, allowing a single point of access for all your field service information. FSM Connect enables fleets and third-parties to create customized applications unique to each fleet needs, benefitting enabled by accurate, real-time information.

Driver Safety module measures and monitors driver behaviour, allowing to Identify and train poor drivers to minimize risk, by combining in-vehicle hardware with a range of real-time alerts, reports and dashboards about driver behaviour that can be utilized by managers and the drivers themselves to improve safety out on the road. Conversely, Trimbles' EU offer for transport and logistics sector lays in its CarCube (on-board computer and display bundle), Truck4U on-board units for both trucks and buses, conceived to operated combined with Trimble mobile applications, and the FleetXPs tablet and mobile App.

CarCube and Truck4U are DIN format on-board units permanently built into the vehicle. The former consists of an in-vehicle unit and a touch screen fitted in the cab as the driver's interface, real-time OTA track & trace, automatic driver identification, safe two-way channel communication, driving time monitoring and display, remote tachograph data download, dedicated heady duty navigation maps and algorithms and FMS data, driving style analysis and driving style display. Additional sensor surveillance and sensor data monitoring can also be accessed using the in-cab display unit.

The Truck4U was conceived having in mind its integration with FleetXPs mobile App. The FleetXPs tablet offers an on-board driver interface that can aggregate FMS data with secondary driver tasks, such as e-CRM, asset tracking and document management, and allows the use of third-party applications tested and certified by Trimble through it smart interface, including forward view, blind spot monitoring and reversing camera. The navigation module specific for heavy duty vehicles determines in real-time, based on traffic information, the safest and most efficient route, helping the driver to focus in its primary driving task. On its turn, the Driving Style Assistant provides drivers with real-time visibility of their driving style and encourages them to make adjustments if necessary, providing an on-going positive effect. On the road warnings, if they exceed the speed limit or if they accelerate or brake harshly or aggressively, against set parameters, bundled with detailed FMS report in FleetWorks so that managers can have clear insights about the impact of drivers' driving style on resulting fuel efficiency and safety critical events. To guarantee safety for vulnerable road users, reversing and blind spot cameras can be directly connected to the in-vehicle computer. Video footage appears on the display when driving at slow speed, in reverse or during turning manoeuvres.

(WABCO) Transics Telematics and Fleet Management Systems

Transics offers Fleet Management Systems (FMS) and services for heavy duty vehicles and driver management, aiming at direct and indirect cost savings, such as fuel savings, optimized driving hours and regulatory compliance. Transics ecosystem includes a comprehensive range of modular services and solutions to address the particular needs of each fleet.

- TX-Connect and TX-Connect MP are respectively web-based and multiplatform back office solutions that manage and display real-time information from drivers and fleets. It enables interaction with drivers, historical views and reporting. It features and SDK for simple integration with other software applications guarantees further processing of your fleet data
- TX-ECO is a brand-independent eco program that evaluates and stimulates driver performance on economic and ecological driving. The program combines in-cabin driver feedback, key performance indicators, driver scores and reporting. Using CAN bus data captured by the on-board computers the solution is fully integrated into the back office software TX-CONNECT. The ECO-ASSISTANT on the on-board driver computer provides drivers with a live overview and daily score on the driving style based on 4 parameters: vehicle speed, engine speed, anticipation (braking) and idling. By gaining real-time insight into their own driving style, drivers are engaged to sustain an optimal driving style.
- TX-GO 2 is a vehicle-independent on-board computer without a display. It is connected to the vehicle digital tachograph, allowing real-time tacho activity follow-up, automated activity management and remote download of mass memory and driver cards. TX-GO

2 is also optionally connected to the CAN bus, allowing fuel management, trend reporting and driver scoring.
- TX-SKY is a powerful, fixed mounted on-board computer with a touchscreen. It is fully integrated into our multifunctional TX-CONNECT back office software and comes standard connected to the vehicle's CAN bus and tachograph. TX-SKY registers all driver and truck information as well as the data from other sources, such as temperature sensors and document scanners. As a secured gateway, TX-SKY also enable the driver and flee-manager to exchange information in real time.
- OptiTire is what WABCO calls a next generation tire pressure monitoring solution for trucks, trailers and buses that is specifically, featuring both driver in-cab alerts, in real-time and fleet managing systems integration. By maintain tire pressure at recommended levels and early detect slow punctures, tire life is maximized and sudden tire failure, that can lead to a major safety critical event, is avoided.

Using TX-SKY provides real-time in-vehicle driver-coaching using ECO-ASSISTANT graphic interface. Alternatively, TX-GO 2 can be using to develop third-party and custom designed driver feedback strategies by collecting CAN bus and tachograph real time data.

VDO TIS-Web Fleet Management

VDO TIS-Web Fleet Management is a modular product and services suite that provides from classical fleet management tools to real-time in-vehicle driver feedback. TIS-Web Motion is a management web-based back-office solution for real-time tracking and efficiency reporting. In combination with the DLD Wide Range II it also provides fleets with advanced fleet management software. The TIS-Web Fleet app provides an interface between the fleet office and drivers. Also, when installed on drivers' smartphones, it receives tachograph data via DTCO SmartLink and sends vehicle, driver and position data, as well as information entered manually by the driver, to TIS-Web. It also offers pre-trip safety checks, where the driver works through a detailed checklist and can record faults with the camera, to be sent directly to head office.

FleetVisor Tyre Control application for FleetVisor records the operating state of the tires via a sensor and forwards the data to head office and the portable DriverLinc tablet from VDO FleetVisor. The tire-pressure monitoring system is based on the ContiPressureCheck and continuously measure the pressure and temperature of all tires and transmit the data to the TIS-Web® Fleet app via Bluetooth. TIS-Web® Communicator module enables Fleet app to establish a two-way communication channel between driver and fleet managers.

In-vehicle VDO DriverLinc tablet can replace the smartphone Fleet app as safe two-way communication with text to speech functionality and integration with VDC Tire Control Service. The DriverLinc tablet is available in three ranges: DriverLinc Light, permanently installed in the driver's cab, and portable DriverLinc and DriverLinc+. While providing professional navigation services with optimal routes for trucks and buses with traffic information in real time, the included Driver Coach provides drivers with a real-time driving trainer, offering overview of engine idling, critical braking manoeuvres, fuel efficiency and other key parameter, which support drivers by providing instant feedback on their driving style compelling them to continuously learn how to drive more economically.

Frotcom Fleet Management System

Frotcom offers a fleet management tool for transportation and bus companies. The company offers a comprehensive suite of services or modules on their platform, including a driver behaviour analysis. The driver behaviour analysis is based on over-revving, engine temperature, usage of cruise control, speeding, and over idling and the metrics can be finely tuned to the fleet needs, by adding weights to the criteria. It also offers as an optional equipment, its DFL Driver Feedback Light Bar that provides the driver with critical real-time information about his driving style using coloured LEDs and acoustic feedback.

Lightfoot Real Time Feedback and Coaching

Lightfoot is a real-time auditory and visual feedback and coaching technology, developed by Ashwoods Automotive, with the goal of helping drivers to improve driving style to be both safer and more efficient. The on-board device provides continuous long-term performance feedback as well as instant performance indicators that offer real-time visual and acoustic alerts once unsafe manoeuvres or inefficient behaviours are identified.

The Lightfoot display unit allows drivers to independently and actively improve their own driving behaviour in real-time through live auditory and visual feedback, actively promoting driving style improvements, rather than retrospectively through substantial data analysis and according to both the manufacturer and insurers. The device provides audible alerts when the driver is not driving in an efficient or safe manner, prompting a change in behaviour. Following three alerts an instant notification will be sent to a representative of your client's choice. Lightfoot allows the driver to be in control because it gives them the opportunity to modify their driving behaviour before any negative data is reported to a chosen representative.

VIRICITI Fleet Management

ViriCity services started with electric buses in mind. The main goal of the system is extending bus operational range, one of the most critical constraints to the deployment of electric vehicles for transit systems.

The services come essentially in packages or modules that focus on:

- Vehicle monitoring
  - Vehicle CAN bus data statistics
  - Route energy statistics and management reports
  - Tell-tale lights and Incident notifications

- Driving style analysis
  - Driver style analysis
  - Energy use and regeneration profile
  - Summary reports and actionable insights

- Remote diagnosis and maintenance management
  - Fault logging overview and diagnostic messages
  - Tire pressure monitoring
  - Brake lining monitoring
  - Auxiliary monitoring

ViriCiti's proprietary machine learning algorithm grades drivers on key performance indicators, providing insight about aspects needing improvement. Driver reports are available per driver or per group to help you train drivers or discuss personal scores. External influences such as weather, road steepness, number of passengers (passenger load), are taken out of the equation for objective results. Although no native real-time feedback is provided by VeriCity product and services range, some of its distribution and public transport costumers use its API and proprietary algorithms running on the DataHub to couple the system with custom designed real-time feedback and driving assistance tools.

All services are based on ViriCity DataHub, an on-board plug and play hardware solution that can be tailored to the specific needs of each fleet. The DataHub streams any amount of CAN bus data in real-time into the cloud. Furthermore, its built-in AppLayer allows fleets to run their own programs and algorithms. ViriCity open API enables fleets and third-parties to develop their own custom applications and integrate complementary fleet management systems and ERP modules.

Verilocation All in one Fleet Management

Verilocation Fleet Management system offers a complete suite of tools for commercial vehicles and buses, ranging from driving time compliance, video-related ADAS for reversing and blind spot monitoring, driver performance analysis to simple video DVR systems. One of the most interesting products offered by Verilocation is its All-In-One Fleet Management Application. The included Driver Dashboard provides to drivers a complete interface to their vehicle for optimised fleet operations, combining mandatory vehicle checks, GPS tracking, tachograph data analysis, ePOD, two-way messaging, job-push with integrated satellite navigation and real-time driver behaviour. The real-time behaviour collects and analyses CAN bus data producing transparent and efficient driving style feedback through handheld or in-cab devices. The Live Performance Feedback encourages drivers to self-assess the efficiency of their driving behaviour. With real-time feedback, drivers are able to recognise the type of incident that signifies a bad driving event for instant on-the-job retraining. End-of-shift debrief also allows them to see their overall shift performance and compare against previous shifts for that week using our simple ‘Efficiency Scoring’ system.

Both real-time in-vehicle feedback and post trip reporting take advantage of 20 key fuel-usage and safety related parameters reported on direct from the vehicle’s engine management system. These data combined with inertial sensors and video cameras deliver a clear a thorough journey insight, matching key driving efficiency related parameters and events such as engine idling, speeding and bad anticipation, with video and contextual evidence. Finally, Verilocation also offers integration with mobile and in-vehicle breathalysers and alcohol interlock systems for enhanced drink driving monitoring and avoidance, compatible with any vehicle type. The solution is designed to immobilise the engine upon the event of a positive breath alcohol (BrAC) reading regarding a fleet customisable threshold.

Zonar Coach

Zonar, as many other telematics providers, has a wide product environment to address the needs of any fleets, from simple tracking to detailed driving efficiency analysis and in-vehicle real-time driver coaching. Zonar features interesting solutions to school and transit fleets, from telematics to passenger tracking, with OD matrix evaluation, and real-time public info. The system gathers CAN bus data (SAE J1708/1587 and J1939 compatible) from its Zonar V4 standard or ruggedized on-board unit that features five I/O expansion ports to extend the telematics core services, which include tracking, odometer and fuel consumption, remote trouble code diagnosis and driver and safety monitoring.

Providing feedback to drivers, about their inefficient and unsafe driving behaviours, is key to continuous improvement. Particularly, instantaneous and continuous driver in-cab feedback increases driver engagement and unconscious behavioural conditioning. To achieve these goals Zonar offer its Zonar Connect tablet unit. The driver's unit provides advanced navigation specific for heavy duty vehicles with safe motion lock function that ensures the driver is focused on its primary task while the vehicle is moving. Parallel to navigation assistance, the Zonar Connect offers real-time in-cab audible coaching complement by event-based driver scorecards.

Visual analytics and inertial sensing event detection triggers acoustic warnings and video recording (Zonar Smart dash camera) for liability assessment and advanced driving training programs. Unlike most in-vehicle real-time coaching devices, Zonar proposition uses video analytics to monitor the road and provide feedback when drivers exceed posted/context speed limits, tailgates, fail to comply with stop signs, lane drift, and evaluate harsh braking, cornering and acceleration rate based on the actual road context. By contextualizing real-time feedback, the system increases driver's engagement and trust prompting the adoption of suggested corrective actions critical to accident avoidance and mitigation. Alternatively, to Zonar Connect display, fleets can make use of Samsung Tab Active 2 and Pro tablets, which can be made fully compatible with Zonar Mobile Ecosystem, including Zonar Coach. Furthermore, the real-time feedback can run additional custom applications for all types of fleets, including commercial trucking, vocational and passenger transportation.

Samsara Driver Safety and Coaching Platform

Samsara Driver Safety and Coaching Platform is a driver's feedback tool integrated with Samsara Fleet Management Platform. The solution is a complete video-based driver safety program, improving driver safety behaviours by using in-cab feedback and video-based coaching that enable safe practices and defensive driving rewarding. By introducing visual contextualization, the Driver Safety Platform also standardizes incident review and driver training with accountability and workflow tools.

Removing location, supervisor or time constraints from the picture, Samsara dash cam in-cab voice coaching for real-time feedback and the dashboard provides optimized step-by-step driver training and coaching workflows for safe, efficient and defensive driving. Furthermore, the Dirver App can complement real-time coaching with advanced navigation assistance from CoPliot or Garmin and with Trimble Telematics solution or Uptake predictive maintenance insights. Open REST APIs unlocks advanced ERP, GIS and public information integration as well as custom tailored reporting and driving feedback and third-party services aggregation.

Driveri

Netradyne is a leader in safe driving systems. The company leverages cutting-edge technologies in Artificial Intelligence, Machine Learning and Edge Computing to help reduce accidents by creating a new safe driving standard for commercial vehicles. Driveri is a vision-based driver recognition safety program that empowers drivers by providing them with enhanced awareness of risky driving behaviour and reward safe driver decision-making. Similarly, to Mobileye it can be installed in light vehicles as well as buses, coaches and trucks.

Driveri GreenZone performance analytics are the industry's first driver's score that is built on the driver's positive driving versus solely focusing on negative events. The whole philosophy underlying the system is the believe that drivers should be measured on their positive performance (positive rewarding/feedback), rather than punished, and provided coaching as needed. However, real-time, in-cab alerts are paramount to driver engagement and seamless behavioural coaching. Driveri RealTimeCoach provides drivers with immediate audible notifications inside the vehicle, helping to proactively reduce risk while the vehicle is moving. Driveri MobileCoach application creates a visual interface with driver, both during driving and post-trip, giving drivers real-time updates on how they're performing and empowering them to engage in safe driving style though valuable and immediate insights, alerts, and notifications about: high g-force events, hard braking and acceleration, traffic signal recognition and violations, stop sign and red light violations, following distance, seatbelt compliance, u-turn detection, speeding violations and driver drowsiness. This feedback advises drivers to adjust as risky events occur, enabling an immediate correction.

Driveri platform also allows for Multiple Camera deployment to enable context awareness and clarity for driver and passenger safety and security. By continuously capturing and analysing all driving events with an intelligent, real-time, vision-based approach, the Driveri external view identifies key risk factors as they occur regardless of g-force or speeding activity, such as contextual over speeding, u-turn manoeuvres, following distance and stop sign violations. Furthermore, side view helps to provide complete context about the surrounding area, enabling drivers to make informed decisions and making up for the limited visibility within vehicle blind spots. An optional internal camera provides a more holistic view of driver and passenger safety and security, identifying distracted driver behaviours and policy violations. Netradyne also develops dynamic 3D/HD mapping solutions, improving Driver Performance with detailed mapping technology for advanced assistance systems. By relying on simultaneous location and mapping, edge computing and crowd-sourcing, Driveri delivers rich, highly accurate content in real-time, critical to the successful development of 3D HD maps and ultimately autonomous vehicles.

iDrive

iDrive provides an intuitive Fleet Management platform called Iris, that monitors in real-time driver's safety and compliance and fleet efficiency. IDrive claims its intelligent platform technology offers predictive analytics and insights that allow real-time detection and driver assessment to prevent accidents and fatalities. It is a AI video-based solution that identifies and logs events in real-time for every driver in your fleet and automatically analyses it into actionable intelligence for fleet managers. Iris intelligence analytics are designed to:

- Understand and profile driver behaviour by identifying and prioritizing the most pressing driver issues with data driven visualizations and performance scores that disclose the full picture of driver behaviours,
- Optimize Driver Performance through data and video supported reporting that uncovers trends and makes tailoring coaching possible.
- Manage Fuel consumption and waste, by tracking vehicle idling and aggressive driving.

The bus and coach solution is complemented by real-time tracking and live telematics information, such as vehicle speed, GPS coordinates, vehicle and driver ids and videos, with an API for integration with third-party services, and a comprehensive video monitoring solution tailored with up to 8 HD video cameras for internal and external coverage for monitoring drivers, passengers, and road hazards. The new AI camera and video analytics keep track on more than 100 driving behaviours and unsafe manoeuvres from harsh acceleration, braking, cornering, lane handling and speeding that are translated into a safety score card for managers to track driver performance by driver, fleet and even a team, and introduces six key features:

- Facial Recognition matches the face captured by the windscreen camera, at the time of ignition, with a template that has previously been logged as authorized driver by the fleet manager. A video event and notification is triggered when the camera cannot match the face to any template in the system, thus prevent unauthorized driving.
- Safe Distance Warning, monitors the traffic context and prompts video events when driver voluntarily breach the safe driving distance from the vehicle in front of them.
- Drowsy Driving Detection detects and monitors the driver's eyelid aperture and determines whether the eye report ratio is according to the driver's unique profile. If the ratio deviates from normal patterns, a recording of the event is captured and in-cab alerts warn the driver.
- Distracted Driving Detection detects distracted driving habits such as smartphone use, texting, eating and more. A distraction is logged when the camera detects that a driver's gaze, facial position and motion falls outside normal driving values.
- Seatbelt Compliance and Aggressive Driving keeps track of seatbelt usage and detects rapid acceleration and consistent braking events through G-force tracking. By fusing video clips with data from 6-axis IMU (accelerometer and gyroscope), that monitors vertical, forward and lateral movements, the report analytics truly delivers the full picture of vehicle activity
- Real-time, in-vehicle alerts provide driver constant AI-powered feedback about his driving style, through acoustic and visual notifications pushed through a small OLED display facing the driver working station. By providing real-time feedback and making drivers aware of fleet managers alert notification, the driver is compelled to adopt a safer and defensive driving behaviour.

Smart Witness Video Telematics for Transit Bus

Video Telematics for Transit Buses record and transmits bus video and location data in real-time. Although not originally conceived to provide drivers with real-time feedback, it has followed market trends and is enabling limited real-time driver feedback. Making use of an optional dashboard mounted LCD display, SmartWitness provides the driver with real-time blind spot monitoring capabilities and 360-degree view of the vehicle surroundings. SmartWitness also offers its DDC-200 fatigue detection and driver distraction alert camera, with facial recognition for automated driver identification. The detection is focused on facial, eyes, mouth and head movements and allows for day and night detection, and features customizable real-time in-vehicle alarm and alerting system. Fatigue Detection includes drowsiness, micro-sleep, or yawning and distraction detection monitors drivers gaze to identify driver behaviours such as texting, hand held use of nomadic devices or eating/drinking while driving.

GEOTAB (and 3rd party integration)

GEOTAB offers a fleet tracking platform that can be complement by apps available thought is digital marketplace. Apart from its own services, GEOTAB capitalises it gateway and platform by leveraging the integration third-party services and expertise. In addition to its own GEOTAB GO unit and platform, GEOTAB offers an SDK and IOX hardware add-ons that enables fast and integration with external sensors and device to its gateway. On GEOTAB market place one can find add-on hardware from many solution providers, including some with proprietary management and data-link offers that can work independently or integrated with GEOTAB platform.

- Since recently, Driveri joined Geotab app ecosystem, offering Geotab customers Driveri driver and safety performance management solution to complement the Geotab fleet management platform.
- As Driveri, SmartWitness is also present on GEOTAB ecosystem, enabling GEOTAB basic and programmable rules to record CAN bus and video event data.
- Seeing Machines, key players in ADAS market for OEM and safety-critical industries such as aviation, offer its Guardian system is seamless integrated with GEOTAB platform and gateway as an aftermarket solution, providing cutting edge real-time accident prevention technology based on superior eye and face tracking software to detect driver fatigue and distraction, and provide immediate intervention through in-cab auditory and vibration alerts.
- Surfsight hardware add-on introduces an AI Powered Connected Dash Cam for capturing and monitoring of driver behaviour in real-time. AI and Computer Vision algorithms automatically detect and alerts distracted driver behaviour and harsh driving incidents in real-time. Furthermore, near misses, collisions, harsh driving events, cargo damage & theft, can also be automatically detected, recorded and uploaded to GEOTAB cloud storage.
- CardioWheel + CardioID Gateway – Unlike most real-time feedback devices, CardioID's CardioWheel focus its real-time monitoring algorithms on the driver state, using non-intrusive ECG techniques and steering wheel angle and angular speed sensor. By measuring the heart rate and its variability coupled with the drivers steering input corrections the system is able to, in real-time, infer driver's attentiveness and drowsiness. Using its proprietary gateway or GEOTAB GO in-vehicle CAN bus gateway, CardioWheel can alerts fleet manager about possible safety risks in real-time. Furthermore, acoustic and haptic feedback can also be used to alert and sensitize the driver about increased driving risk, resorting either to GEOTAB GO or CardioID's proprietary gateway I/O expansion ports. Additionally, using GEOTAB vehicle CAN bus data, basic aggressive driving feedback can be optionally made active.
- Movo's MDAS Advanced Collision Avoidance and DVR System add-on offers a collision avoidance system with DVR to document safety-critical events. MDAS is an advanced driver assistance system, designed to prevent accidents while drivers are driving by assisting drivers through several key features:
    - Pedestrian Collision Warning (PCW)
    - Front Vehicle Collision Warning (FCW)
    - Unintentional Lane Departure Warning (LDW)
    - Safe Driving Distance Alarm (SDA)
    - Front Vehicle Start Alarm (FVSA)
    - Embedded Video Recording Function

  The Forward Collision Warning System alerts the driver using both auditory and visual warnings when their vehicle is approaching to the vehicle ahead too quickly. The Time to Collision warning lets drivers know the time it would take to collide with the car in front of them. Both vehicle and non-vehicle 'obstacles' can be detected, including pedestrians. The Lane Departure Warning System detects different types of lane markings and colours, warning the driver once they unintentionally depart from the lane they are in.

  A key advantage of MDAS when comparing to MobilEye-like solution is that it also provides dash cam features with embedded video recording, that enables post trip analysis of driving behaviour through the information collected in reports and by creating rules and exception that prompt real-time alerts to coach driver and trigger detailed event logging.

- E-Horizon Road Weather Hazard Alert Service is a proactive accident avoidance system that transmits acoustic and visual warnings of weather-related road hazards to both dispatchers and drivers. E-Horizon provides a full toolkit for fleet managers and telematics service providers to manage the impact of weather hazards on fleet logistics, providing real-time view of road and weather conditions to enable direct action, reducing driver risk, and a map-based service to review real-time hyper-local, weather-related road hazards and risks. Using data fusion techniques, the system generates automated real-time auditory and visual alerts of road weather hazards in proximity to the vehicle that are transmitted directly to the driver, concerning: hydroplaning risk (flooding/precipitation), low visibility risk (fog), icing risk (black ice/frozen rain), wind and gust risk, hail and lightning risks.
- ContiPressureCheck, from tire and ADAS manufacturer Continental, is a tire pressure monitoring system for commercial vehicle fleets. Its unique system uses sensors mounted inside the tire to capture the most accurate tire temperature and pressure data, and inform the driver of tire related issues in real-time, lowering tire-related maintenance costs and improving road safety and fuel efficiency.
- PressurePro’s Tire Performance Management Solutions provide fleets with the real time tire pressure and temperature information needed to add safety, savings and efficiencies to fleets. Fully integrated with GEOTAB solutions, PressurePro enables users to remote monitoring and logging tire condition using GEOTAB platform and providing both instant in-cab and remote alerts.
- PreView Sentry is a radar-based collision avoidance system that provides operators with a visual and audible alert when a person or object is detected in the designated detection zone. The Sentry sensor is installed on the exterior of the vehicle or equipment at the midpoint of the blind spot. The system features a simple LED display that is mounted inside the cab for real-time feedback with possibility to add video monitoring functionalities.
- Along with many competing systems, Mobileye Collision Avoidance System can be deployed as an aftermarket solution seamlessly integrated with GEOTAB. The Collision Avoidance System warns drivers of the risk of a collision in advance. A couple of crucial seconds can mean the difference between a devastating collision and an incident entirely avoided or considerably less severe. The system works by continuously monitoring the road ahead and analysing potential risks of forward collisions, unintended lane departures, tailgating, and pedestrian and cyclist hazards. The system can differentiate between vehicles, pedestrians, and cyclists, while also recognizing lane markings and offers speed limit sign recognition.

MobilEye

Mobileye is a key player in driver assistance systems and autonomous driving development. It features both aftermarket solutions for car and fleet retrofit as well as OEM and Tier-1 hardware and software suites. Advanced Driver Assistance Systems range on the spectrum of passive and active solutions. Aftermarket products are mostly passive systems, alerting drivers of a potentially dangerous situation advising driver to take corrective actions. Lane Departure Warning (LDW) alerts the driver of unintended or unindicated lane departure and Forward Collision Warning (FCW) indicates that under the current dynamics relative to the vehicle ahead, a collision is imminent, whereas Pedestrian Collision Warning (PCW) monitor and alters about risk of colliding with vulnerable road users. Traffic Sign recognition also warn drivers about local traffic rules and speed limits enhancing driver’s compliance levels.

Mobileye aftermarket products offer life-saving warnings in a single bundle, protecting the driver against the dangers of distraction and fatigue, providing a warning-only systems that can be retrofitted onto any existing vehicle, including hardware designed proposedly for buses and trucks. In contrast, OEM offer active safety systems that require integration with the vehicle actuator and controls. Automatic Emergency Braking (AEB) uses FCW and PCW to identify imminent collisions and brakes without any driver intervention. Adaptive Cruise Control (ACC), Lane Keeping Assist (LKA), Lane Centering (LC), and Traffic Jam Assist (TJA) ISA (Inteligent Speed Assistance) depart from the continuous monitoring functions offered by passive systems and autonomously adjust The MobilEye 6 and 8 Connect offer frontal collision and lane departure warning, vulnerable road used warning, speed limit indication and headway monitoring. The system is composed by a camera unit, a CAN bus interface and the EyeWatch display that provides continuous visual feedback and graphic and acoustic alerts whenever a hazardous situation in detected.

The new connected system (MobilEye 8 Connect) uses driver behaviour and alert data, environmental changes (both rad and weather) and crowdsourced notifications to intelligently adjust alert configuration. Mobileye 8 Connect systems regularly receive over-the-air software updates that add new safety features and improve its existing functionality. The new Fleet Management tool allows for optimised routed planning by avoiding critical-safe hotspots, produce in-depth safety reports, related to safety alters for driver behaviour monitoring and coaching, and remotely adjust alert trigger thresholds through a simple web-based interface.

Designed specifically for heavy-duty vehicles that work within city centres, Mobileye offers the MobilEye Shield+. On top of standard features the system adds external cameras for Blind Spot Detection that warns drivers that a pedestrian, cyclist or motorcyclist has been detected in the vehicle's blind spot. The pedestrian and cyclist blind spot warnings use two LCD displays, showing a yellow signal is given to advise caution and a red alert is triggered in case off an imminent collision for immediate preventative action.

MiniEye

MiniEye offers OEM and Tier-1 hardware and solutions that compete with MobilEye using computer vision and deep-lerning and neural-network techniques. Its Environment Sensing self-developed visual sensing system is able to precisely detect free space and various traffic objects, including vehicles, pedestrians, lanes, traffic lights and sighs. The in-cabin Sensing visual sensing and sensor fusion power by neural-networks assesses the conditions and behaviours of passengers and drivers through monitoring eyelid, gazing direction, movement of head and body, and in-cabin objects. MiniEye aftermarket products include:

- Dongfanghong Intelligent Video Monitoring Terminal, integrating ADAS, Driver Monitoring System, GPS, wireless transmission and car DVR, supporting WIFI and 4G communication.
- Long March 3 Intelligent Driving Monitoring Terminal, designed for commercial vehicles, provides a cost-effective driving safety warning product, integrating ADAS, Driver Monitoring System and Blind Spot Detection, with cellular wireless transmission, DVR.
- Long March 5 Intelligent Driving Monitoring Terminal, focused on car-hailing industry, Long March 5 is a vehicle-mounted intelligent monitoring product with an integration of ADAS, Driver Monitoring System and Blind Spot Detection, with cellular wireless transmission and DVR.

MiniEye Driving Monitoring Cloud Platform is based on driving warning data, real-time video transmission and location information of vehicles and integrates active safety, video monitoring, vehicle position monitoring, data analysis and operation management.

IntelliVision AI and Video analytics ADAS product suite

Advanced Driver Assistance Systems (ADAS) have helped improve safety for road users by complementing the actions of drivers. But until recently, most systems were only available on new vehicles. IntelliVision provides similar features available for OEMs to build into aftermarket solutions. The IntelliVision ADAS product suite is an aftermarket camera-based solution for aftermarket, integrators and OEMs. A simple camera running analytics software, mounted on the windshield of any vehicle, turns into a powerful and flexible driver assistance solution. Algorithms and outputs are customizable, and the software architecture is adaptable and portable onto mobile platforms. Key Features of IntelliVision ADAS product suite:

- Forward Collision Warning (FCW) that detects a potential collision condition with the preceding vehicle in the driver's lane. Time-to-collision (TTC) and Headway are computed and if below a safe threshold, alarms (acoustic, LEDs, HUD display, haptic feedback) are triggered to alert the driver.
- Lane Departure Warning (LDW) continuously monitors lanes on the road and alerts the driver to deviation. LDW can be programed to alert the driver to unintentional lane departure - left or right. With a selection of feedback options the driver is instructed to refocus attention and entail necessary corrective action.
- Pedestrian Detection and Zero User Setup
- Traffic Road Sign Detection

Additionally, Blind Spot Monitoring and Vehicle Detection and Smart Mirror features are currently under development.

Safe Drive Systems

Safe Drive Systems offering enforces fleet safety with an advanced radar fleet management and collision prevention and avoidance system. Safe Drive Systems are the leading developer of a unique aftermarket radar and camera based collision avoidance system that integrates with a fleet management system. The Safe Drive Systems Fleet Manager Dashboard provides safety scores that grade drivers with a custom safety score through detailed vehicle-by-vehicle reports that compile pedestrian warnings, forward collision warnings and more. Using the only aftermarket 2-in-1 radar and camera fusion system, Safe Drive Systems effectively predicts and prevents transportation and logistics accidents. The radar provides complementary visibility when the camera sensors are compromised by adverse weather conditions, both day and night, a key advantage over competing solutions. The Mobile App an in-vehicle real-time alerts keep drivers engaged and aware of what's ahead, up to 150 meters, or around 5 seconds, in advance.

Broadmann 17 Active Safety Software Suite

Brodmann17 offers a comprehensive range of ADAS suites, ranging from Front Active Safety Software and Surround Camera ADAS Suites to a Passive aftermarket ADAS Software Suite, providing the essential building blocks to critical advanced and active driver assistance. The Front Active Safety Suite offers advanced object recognition and tracking, including the detection of vehicle, pedestrian and other vulnerable road users, lane tracking and involuntary departure, accurate (distance) ranging and time to collision estimates, enabling the critical safety awareness features, namely:

- Forward Collision Warning that monitors the road ahead and alerts the driver of an imminent collision with other vehicles,
- Lane Departure Warning based on lane markings on the road tracking that alerts the driver whenever the vehicle unintentionally drifts from its lane,
- Pedestrian Collision Warning that scans the road and sidewalks and alerts the driver of an imminent collision with pedestrians or cyclists.

When integrated with vehicle actuators, these systems enable the deployment of advanced active systems, such as:

- Adaptive Cruise Control, which scans the road and automatically adjusts pre-set cruise control speed in case of a slower vehicle ahead,
- Autonomous Emergency Braking that monitors the road ahead and automatically brakes without driver intervention in case of an imminent collision,
- Lane Keep Assist tracks lane markings on the road and automatically steers the vehicle back into its lane whenever it unintentionally drifts out of lane, and
- Traffic Jam Assist and Highway Pilot, fusing ACC and Lane Centring algorithms to allow the driver to relax while the car takes the wheel. relieve the driver in traffic jam conditions

Brodmann17 offers surround view ADAS software that uses ground-breaking AI to provide alerts with 360-degrees' coverage. It is provided either as a complete black-box solution trained on extremely challenging weather conditions and scenarios or tailor-made for specific applications. Using NXP or Ambarella image processors, Brodmann17 deliver a software stack for advanced driver assistance systems and automated driving up to 4 cameras with a 20-meter range and 360-degree coverage. For aftermarket retrofitting Brodmann17 offers its comprehensive deep-learning solutions but is restricted to passive warning systems. The Brodmann17 Aftermarket ADAS Software Suite was especially created for emerging aftermarket devices that offer ADAS functionality on top of basic dash-camera and telematics functionalities, ideal for tailored fleet management and driver scoring. The software is designed to use with available resources in existing dash cameras, commonly based on Ambarella, Samsung, or Qualcomm SoCs. It employs a mono camera and 2-8 cores, depending on the exact SoC version and remaining processing and memory resources. Its solution, which is completely based on deep-learning AI, is made available by ground-breaking deep-learning technology based solely on ARM cores. The aftermarket ADAS system is provided either as a full pre-trained-solution or tailor made for your specific setup, camera, and lens to provide safety awareness features, namely:

- Forward Collision Warning,
- Lane Departure Warning, and
- Pedestrian/Cyclist Collision Warning

<u>CUB ELECPARTS TPMS and ADAS</u>

CUB ELECPARTS is a Tier-1 and Tier-2 automotive components producer supplying both OEM and aftermarket solutions. It develops ADAS systems based on its own millimetre Wave Radar core technologies, and is capable of customized design according to required performance and applications, that offers Blind Spot Detection, Rear Cross Traffic Alert, Lane Departure Warning, Forward Collision Warning and Parking Assist.

<u>ACTIA Telematics, Fleet Management and DriverAid</u>

The Automotive division of the ACTIA group represents almost 90% of the group's turnover and develops embedded systems and vehicle diagnostics. As Europe's leading supplier of telematics equipment for commercial vehicles ACTIA offers on-board telematics platforms (TGU range commercial and industrial vehicles and ICAN and ACU range for light vehicles). The Telematics Gateway Unit (TGU) is equipped with latest generation mobile communication capabilities, including WiFi, Bluetooth and 4G, for wireless communication of data, collected from on-board ECUs (via CAN, FMS buses or Ethernet), and vehicle positioning. ACTIA's fleet management solutions for city buses and coaches seeks optimizing safety, comfort, environment and management, providing services:

- Eco-driving: monitor fuel consumption, real mileage covered, CO2 emissions, driving behaviour, etc.,
- Advanced maintenance and management with electronic vehicle data logging for diagnostics and maintenance functions, etc.,
- Activity data and driving times monitoring with remote retrieve of tachograph data from the driver cards and the vehicle tachograph unit.

These solutions rely on on-board equipment that can be coupled with DriverAid display. Driver Aid driving assistance display, as an accessory for aftermarket or integrated into dashboard, relays the eco-driving functions, so that drivers can monitor fuel consumption improve their performance. Using CAN or FMs data to monitor real time engine data, fuel consumption, speed, accelerator and braking the DriverAid display provides real-time feedback directly to the driver using LEDs and acoustic warnings (aftermarket) or customized visual and acoustic solutions for OEM and dashboard integration.

WABCO aftermarket (and OEM) ADAS

WABCO is a leading Tier-1 automotive supplier with a comprehensive range of ADAS solutions for OEM and aftermarket.

- OnLane Lane Departure System is part of OnLane family of products, supporting bus and truck drivers in avoiding unintentional lane drifting. WABCO and SmartDrive have teamed up to provide an exclusive safety package that utilizes the OnLane camera for video safety recording. By capturing risky driving performance as it occurs, and providing fleets with critical safety insights.
- OnLane Alert Lane is a camera-based lane departure warning system. The system utilizes a forward-looking windshield-mounted camera with a 77-degree field of view capable of monitoring and calculating the vehicle's position within the lane. When the system detects the vehicle crossing lane markings without the turn signal being activated, the system warns the driver, in real-time, on unintentional lane drifting using acoustic feedback.
- OnGuardACTIVE is a radar-based active safety Advanced Emergency Braking system that offers Collision Mitigation, Adaptive Cruise Control and Forward Collision Warning. The system employs a 77GHz long range, high precision forward-looking radar to detect moving, stopped or stationary objects up to 200 meters ahead, and warns the driver of a possible collision by providing audible, visual and haptic real-time warnings. The system ACC, while in cruise, estimates time to collision with the moving vehicle in front and automatically adjusts speed to conserve a safe (3.6 seconds) following distance behind the followed vehicle. When needed, the system will also actively apply the brakes to help avoid or mitigate a collision. Alerts can be integrated into Telematics and WABCO ADAS suite with customizable parameters.
- OnGuard Collision Mitigation System was introduced to the commercial vehicle industry in 2008. OnGuard assists drivers in recognizing and responding to hazardous situations. The system has been trained with driving scenarios that could lead to a rear-

end collision and provides Forward Collision Warning, Active Braking, and Adaptive Cruise Control capabilities.

- OnGuardMAX Advanced Emergency Braking System is WABCO's next generation collision mitigation system designed to introduce Pedestrian Detection, ACC Stop & Go to capable systems.
- OnSide Blind Spot Detection is a radar-based system that monitors the vehicle's passenger side blind spot, supporting drivers during merging into adjacent passenger side lanes by checking them for clearance to help avoid side collisions lanes and lane change manoeuvres. When a moving vehicle is detected in the monitored blind spot, the system provides a visual warning through a display mounted on the passenger side A-pillar.
  The system works above 20km/h and its unique algorithm filters out stationary objects, eliminating false detections, providing a 160-degree range and 15 meters of coverage, including a 10 meter rearwards detection.
- OnSideASSIST combines WABCO's active steering technology, forward-looking camera and a side-mounted radar for active blind spot correction. The system constantly monitors the vehicle's passenger-side blind spot and if necessary, provides an assistive torque to support the driver in avoiding side collisions even in low visibility conditions.
- TailGUARD Rear Blind Spot Detection System detection system monitors stationary and moving objects behind the vehicle and activates vehicle brakes to help prevent collisions. The system, activated when reversing, monitors stationary and moving objects up to a distance of 2 meters behind the vehicle and is able to vehicle brakes and prevent collision

Aftermarket Tire Pressure Monitoring Systems

Tire Pressure Monitoring Systems are viewed by EU regulations as critical driver assistance systems regarding fuel efficiency and road safety, to such extent that they are to become mandatory for new buses and trucks type approval. Many OEM, Tier-1 and Tier-2 manufacturers offer aftermarket solutions with varying degree of integration with vehicle dashboard and OEM interface or, alternatively relying on external displays to relay tire pressure, temperature and, in some cases, estimated wear (e.g. Pirelli Connesso aftermarket tires, Goodyear, etc.). Some aftermarket TPMS solutions, mostly conceived for cars and motorcycles, provide also integration with driver's nomadic devices through mobile apps. Goodyear, Continental, Michelin, Pireli, WABCO, ZF, Bendix, CUBS, among many others, including white label solutions, are available for retrofitting in buses at moderate costs, relying either on internal or external Tier-1 to Tier-3 pressure sensors manufacturers and conveying continuous pressure and temperature monitoring and driver feedback, with graphic and acoustic driver notifications whenever tire pressure or temperature levels exceed of fall below the manufacturer-defined safe operational interval.

White label and alternative manufacturers Aftermarket ADAS

Akin to aftermarket TPMS, currently many less known manufacturers provide a wide range of ADAS with real-time driver feedback. Most of these systems can even be found as white label solutions. Smartcomm, Road iQ, Howen, Stonkam, DesignCore, Oraclo are only a few examples of companies that use either camera, radar or a combination of both to monitor and provide, in real-time, visual and acoustic feedback to drivers concerning: Driver Monitoring (drowsiness, distraction, etc.), Blind Spot Vehicle detection, Lane Departure Warning, Forward

Collision Warning, Safe Distance/Headway monitoring, 360-degree surround video or Camera mirrors.

D.8 Trains

D.8.11 Visual

Train Protection Systems (TPS) use train detection and movement authority to ensure and safeguard train operation (Connor and Schmid, 2019). They are also designed to reduce risk of driver error leading to a train movement related accident. This advanced system uses cab signalling, where the trains constantly receive information regarding their relative positions to other trains. According to Connor and Schmid (2019) some systems only intervene in the event of a visual signal being passed at danger (SPAD). It should be noted that a signal passed at danger, known as running a red signal, is an event on the railway where a train passes a stop signal without authority.

In addition, automatic brake application occurs if the driver fails to acknowledge a warning. Some systems act intermittently but the most sophisticated systems provide continuous supervision. Additionally, there are both continuous and intermittent Train Protection Systems. For instance, Automatic Warning System (AWS) provides train drivers with an in-cab visual warning and reminder that they are approaching a distant signal at caution (Connor and Schmid, 2019). The driver has to ‘cancel’ the warning (i.e. respond to the warning signal), otherwise train brakes are applied automatically. However, train drivers might just learn to respond to the signal as a reflex rather than being alert and vigilant.

Moreover, Train Protection and Warning System (TPWS) was developed for British main-line railway system (Connor and Schmid, 2019). This train protection system applies full brake application if the speed limit is exceeded or when a train goes past a stop signal. It was also designed to enforce the observance of speed restrictions and signal stops. TPWS reduces the speed with which a train approaches a signal if the driver failes to reduce the speed to allow them to stop at the signal. The system would slow or stop the train regardless of any action or inaction by the driver. TPWS is not designed to prevent SPADs but to mitigate against the consequences of a SPAD, by preventing a train that has had a SPAD from reaching a conflict point ahead of the signal. It aims to reduce SPADs. Finally, it is worth mentioning that AWS was constantly retained with the TPWS system, so drivers received signal warnings.

D.8.12 Combinations

Some systems included audible or visual indications inside the driver's cab to supplement the lineside signals. Automatic Train Protection (ATP) is a type of train protection system (Connor and Schmid, 2019). The ATP systems continually monitor actual speed and enforce speed limits. Speed is monitored against current permitted limit, and if the speed limit is exceeded and reaches the intervention curves, an emergency brake is applied until the train has slowed down or stopped. Additionally, if the train exceeds the warning curve speed, the driver receives an auditory and visual warning. Train data such as weight, length, braking capability and maximum speed are needed to ensure speed limit compliance in line with the ATP system.

Annex E: Detailed Literature review of post-trip interventions

E.1 Cars

E.1.1 Visual

Freematics and OnStar are examples of two telematic recording devices that brought freedom to vehicle telematics projects involving OBD-II, GPS, MEMS sensor and wireless technologies with open-source hardware providing visual feedback to driver (Tselentis et al., 2017). The method of data transmission to a Control Centre varies, an installation which a series of operations is directed and is usually based wirelessly from a Bluetooth Low Energy device and a Serial Port Profile (SPP) module, designed for serial communication and built-in the OBD, through a microSD card, or using car-to-car communication automatic through GPS. The indicators that are recorded by each device are targeted at performance and driving behavioural characteristics, such as distance, time, location and speed, acceleration or harsh braking.

Sky-meter is another telematic manufacturer that measured additional information, such as the location and parking duration via a GPRS/CDMA network and displayed visual magnitudes per square arc second (Tselentis et al., 2017). After the end of a trip, a medium fidelity, fixed-based simulator powered by Global Sim Inc.'s DriveSafety™ was utilized and drivers received a trip-report with visual alerts about their dangerous driving using yellow for distraction level and orange-light notifications for severity level (Donmez et al., 2008). Drivers also seemed to accept this kind of feedback. The visual reports were found to be useful and satisfactory.

Toledo and Lotan (2006) developed a driving simulator study and the results proved that the exposure to post-trip interventions viewed from an IVDR system called DriveDiagnostics, as printed reports or through a dedicated website had a positive effect on driver performance and therefore safety. Furthermore, access to the feedback provided by the DriveDiagnostics system could further affect driver performance in the desired direction. Moreover, Usage-Based Insurance (UBI), also referred to As Pay-Per-Mile (APPM), Pay-As-You-Drive (PAYD), or Pay-As-You-Go (PAYG), was a type of auto insurance that could motivate the driver to drive safer (Tselentis et al., 2017). UBI was often powered by telematics and provided insurers with a range of data, from how drivers were braking and accelerating to their speeds, where they were driving, and for how long they were behind the wheel. Another research (Dijksterhuis et al., 2015) examined the PAYD insurance system. Participants in this driving simulator study were provided with delayed visual feedback through a website. Results indicated improved driving behaviour for users. According to Bolderdijk et al. (2011) PAYD was effective in reducing speeding across all road types but less effective at 30 and 120 km/h roads and there found an awareness of being monitored faded as time passed and speeding returned to its 'natural' level.

In a study of Roberts et al. (2012), conducted to evaluate post-drive mitigation systems, which were designed to reduce driver distraction, results indicated that informing drivers for their driving performance after driving, was more acceptable than warning them with auditory and visual alerts while driving. Post-drive feedback was an effective tool to promote safe driving behaviour. The system was comprised of a report card with multi-level feedback about the driver's distraction level, a video of distracted driving from the completed trip and related performance and behavior measures. Participants also received a distracted driving score at the end of their trip. Moreover, a very interesting finding of Payyanadan et al. (2017) recorded driving behaviour of older drivers using in-vehicle data recorders and provided feedback using web-based Trip Diaries. Results showed that post-trip interventions reduced the estimated route risk of older drivers by 2.9% per week and their speeding frequency decreased on average by 0.9% per week. Providing drivers with tailored feedback of their performance and crash risk helped them appropriately self-regulate their driving behavior and improve their crash risk outcomes. According to Ando and Nishihori (2012) drivers received visualization and records of their driving performance by e-mail. The information was provided through website and the driving data were collected by the Behavioural Context Addressable Loggers in the Shell (BCALs) which was put on the car's dashboard. Reasons for adopted the BCALs were its relatively low cost and its relatively high performance.

Data devices, such as GPRS-based technology, was utilised to monitor driving speed and a weekly graphical feedback report of a safety profile was given to the drivers in Newnam et al., (2014). Although a 75% reduction in speeding violations was revealed after receiving feedback, there was also an inconsistent pattern of speeding behaviour throughout the implementation of the feedback and goal setting exercises. A separate Android-based application with a CAN-Bus simulator ("OZEN 1610"), was developed to ensure traffic safety or navigation and enabled remote control capability by displaying virtual graphical information on a mobile panel in Teng et al., (2011). By the parameters shown in the mobile, drivers monitored the car's information effectively and synchronously and this therefore enhanced the vehicle's safety. Furthermore, in Toledo et al., (2008) a post-trip application and web-based reports summarized and compared information at the level of the driver. Visual reports included statistics of the total hours of driving during the month and comparison of the driver's performance to previous months and to other drivers in the fleet. IVDR provided relatively cheap and continuous measurement of on-road driving behavior and vehicle usage, which was otherwise difficult to observe. The results demonstrated the potential usefulness of IVDR systems.

E.2 Trucks

E.2.1 Field trials and case studies

In light of the original i-DREAMS proposal, the primary interest regarding pre- and post-trip interventions is in the use of in-vehicle behavioural monitoring (i.e. project Pillar I) combined with pre- or post-trip (persuasive) feedback (i.e. project Pillar II). However, based on the literature investigated, three important observations could be made. Firstly, to the best of our knowledge, there is not much (not to say only very few) research available where, based on an experimental study design, interventions combining in-vehicle behavioural monitoring and pre- or post-trip feedback to promote road safety and/or eco-efficiency among professional operators of heavy vehicles, has been examined in a 'stand-alone' setting. Therefore, it remains difficult to draw conclusions on the net impact of such an intervention on road safety and/or eco-efficiency among professional truck drivers. Secondly, almost none of the studies that did focus on interventions combining in-vehicle behavioural monitoring and pre- or post-trip feedback to promote road safety and/or eco-efficiency among professional operators of heavy vehicles in a 'stand-alone' setting, were performed in a real-life setting, but in a traditional 'in-lab' context. In terms of ecological validity, it is still open for discussion to what extent findings from in-lab studies can be generalized to daily life reality. Thirdly, based on the outputs from the literature on occupational health and safety management, it is recommended to work on the improvement of road safety and/or eco-efficiency of employees by means of a combination of different interventional approaches, rather than to focus on one, or a few isolated countermeasures. The most important findings are summarized. This will be done in two separate sections, in which a cross-modal perspective in a sense that findings will be brought together from different areas of transportation (i.e. road, rail, aviation and maritime). Conclusions for heavy vehicle fleet interventions with a VMS-component are made which focus on findings that apply more specifically to truck drivers

In addition, the article databases of a series of academic journals were systematically screened in the field of road safety and transportation (e.g. Accident Analysis and Prevention, Safety Science, Transportation Research Parts A, C, D and F, Transport Policy) to look out for relevant publications. A first screening resulted in a total of 30 potentially relevant references. Three of these were directly relevant since they specifically referred to the kind of study design looking for, i.e. field trials (preferably based on an experimental design) where interventions to promote road safety (preferably with inclusion of an intervention component combining on-board behavioural monitoring with pre- or post-trip (persuasive) feedback) were applied to professional fleet operators (preferably heavy vehicle drivers) in the authentic daily life working context.

The first key-reference, was an extensive multi-modal review study by Nævestad et al. (2018), focusing on the impact and influencing factors of interventions aimed at the improvement of safety culture in transport organizations. In total, the authors identified and analyzed into detail 20 safety interventions. Five interventions related to air transport (see Table 20 in Nævestad et al., 2018), three interventions were situated in the maritime sector (see Table 22 in Nævestad et al., 2018), four interventions related to rail transport (see Table 21 in Nævestad et al., 2018), and eight interventions applied to the sector of road transport (see Table 19 in Nævestad et al., 2018). Three out of the eight studies in the domain of road transport had truck operators as part of the targeted population.

The second key-reference was a study report for the National Surface Transportation Safety Center for Excellence (NSTSCE) in the US on effective strategies to improve safety among commercial motor carriers by Camden et al. (2019). The authors recruited nine carriers to participate in an hour-long interview to document the strategies they used to improve their safety outcomes, based on real-world data. These interviews were content-analyzed and the top performing strategies across the nine carriers investigated were brought together in an overview table that was based on the Haddon Matrix, thus linking specific intervention strategies to vehicle-, employee-, environment- , and management culture-related targets in a pre-crash, at scene, and post-crash setting (see Table 23 in Camden et al., 2019).

The third key-reference was a policy paper by the Royal Society for the Prevention of Accidents (ROSPA, 2013: p. 23-30), offering a comprehensive overview of company case studies and field trials where telematic technology was used as (part of) an intervention strategy to promote the road safety of professional fleet drivers. This overview resulted in the identification of an additional eleven studies, all situated in the field of road transport, three out which included truck operators.

Al together, this resulted in 40 studies to be subjected to a detailed review (i.e. 5 from aviation, 3 from maritime, 4 from rail, 28 from road transport out of which 15 included truck operators).

Analysis

In terms of how the 40 studies retained for review were analyzed, the approach was adopted followed by Nævestad et al. (2018). In other words, for each of the studies involved, the reporting source is mentioned, the transport mode examined (for road transport studies, indicated whether or not truck operators were involved), the country where cases or field trials too place, the context of the intervention implemented, more specific details about the intervention approach itself, whether or not the intervention implemented included (behavioural-based) in-vehicle monitoring as one of its components, the evaluation design used, and impact on safety. For the 29 studies that were already reviewed and analyzed in detail by Nævestad et al. (2018) and by Camden et al. (2019), the findings were simply kept as they were reported by the respective authors. For the 11 additional studies, identified based on the policy paper by ROSPA (2013), the beginning was from information reported in that policy paper in combination with our own readings and interpretation of the studies in question.

Findings

All the above mentioned information was brought together in four different overview tables. In **Error! Reference source not found.** presents the findings for the 28 studies situated in the field of road transport. For studies already analyzed by Nævestad et al. (2018) and by Camden et al. (2019), the findings are indivated which contained in the table are drawn from these two respective sources. Table 25, focuses on the five studies in aviation and is a reproduction of Nævestad et al. Table 26 presents the findings for the four rail-related studies, and is a reproduction of Nævestad et al. Table 27 summarizes the findings for the 3 studies in maritime, and is a reproduction of Nævestad et al. Finally, Table 28 specifically concentrates on trucks, and is a reproduction of the summary overview table by Camden et al.

Table 24: Field trials and case studies implementing interventions to promote occupational road safety in road transport: based on Nævestad et al. (2018), Camden et al. (2019)

ROAD TRANSPORT								
SOURCE	**TRANSPORT MODE**	**COUNTRY**	**CONTEXT**	**INTERVENTION APPROACH**	**IVMS-COMPONENT INCLUDED?**	**EVALUATION DESIGN**	**IMPACT**	
Gregersen et al. (1996)	Road	Sweden	Effects of 4 organizational interventions on road safety among drivers in the Swedish company Televerket. Interventions expected to influence safety culture included: (1) driver-led group discussions, (2) a 1-year company road safety campaign.	Group discussions: drivers work together to discuss safety problems, identify solutions, make an action plan, and act. Discussions and resulting measures evolve in several sessions over several months. Company safety campaign: presentations, information, visible campaign logo etc.	Not clearly specified	Robust, quasi-experimental prospective design, with measures of treatment and control groups for 2 years before and 2 years after the interventions. Five groups of company drivers (n= 900-1000 in each group) with 4 test groups and 1 control group.	Significant reductions in accident risks for driver training and group discussion interventions, from 0.16 to 0.08 accidents caused by company drivers per 10,000km driven. Greatest accident cost reductions seen for group discussions.	This information is taken from Nævestad et al. (2018)
Lehmann & Cheale (1998-1)	Road	US	A school bus operator in the US fitted half of its school bus fleet with a black box and compared it with the other half of the fleet that were not fitted with a black box.	Not specified	Yes, black box	Not specified	The buses without a black box accounted for 72% of the fleet's accidents over a six month period. The authors concluded that 19 accidents were prevented by the use of the black boxes, which resulted in a saving of $76.000 in vehicle repair costs.	
Lehmann & Cheale (1998-2)	Road	Germany	Berlin Police fitted ADRs to 62 squad cars in 1996.	Not specified	Yes, an ADR	Not specified	After installation of the ADRs, the number of accidents due to the driver's own fault fell by 20% and by 36% on emergency-trips. Cost savings were approximately 25%.	
Lehmann & Cheale (1998-3)	Road	Germany	WKD Pinkerton Security GmbH fitted approximately 100	Not specified	Yes, an ADR	Not specified	Following the installation of the ADRs, accidents decreased by 30%, minor damage accidents by	

			pool company cars with ADRs.				60% and led to considerable savings in insurance premiums.	
Lehmann & Cheale (1998-4)	Road	Germany	A German bus operator fitted ADRs in 123 buses.	Not specified	Yes, an ADR	Not specified	After installation of the ADRs, the number of accidents decreased by between 15 and 20%.	
Lehmann & Cheale (1998-5)	Road	Great Britain, the Netherlands, Belgium	Nine vehicle fleets with a total of 341 vehicles were fitted with data recording equipment as part of the SAMOVAR (Safety Assessment Monitoring on Vehicles with Automatic Recording) project.	Not specified	Yes	Not specified	Over a 12 month period the accident rate decreased by 28%	
Wouters & Bos (2000)	Road (trucks included)	Belgium & the Netherlands	This study involved 840 vehicles, 270 of which were fitted with either an Accident Data Recorder (ADR) or a Journey Data Recorder (JDR) in 11 fleets. It was assessed whether this improved driving behaviour and reduced accident risk.	Drivers were told if a recorder was fitted in their vehicle and that its prime purpose was to help them to adapt their driving behaviour. For recording driver behaviour data, two types of commercial recorders were used. One of these was the 'accident data recorder', designed to collect data just before and during an accident or incident for the purpose of facilitating the reconstruction of the event. The other type of recorder was an on-board computer or journey data recorder, collecting data on time schedules, mean	Yes, for recording driver behaviour data, two types of commercial recorders were used. One of these was the 'accident data recorder', designed to collect data just before and during an accident or incident for the purpose of facilitating the reconstruction of the event. The other type of recorder was an on-board computer or journey data recorder, collecting data on time schedules, mean speed, rapid acceleration & decelerations, fuel consumption as well as driving speeds over the last 90 seconds before the vehicle stopped.	Quasi-experimental field trial. Accident data for the 12 month period before the equipment was installed was compared to the data during the period that the recorders were installed. The vehicles were divided into 7 groups (Ato G) with vehicles fitted with a recorder being matched with one or more control groups. During the study period, the 840 vehicles, 270	The effects of the monitoring devices varied between the groups. Group A was 110 heavy trucks in an international transport company fitted with ADRs and matched with 50 similar trucks in the company and 105 similar vehicles from another similar company that were not fitted with an ADR. Accident rates for vehicles fitted with an ADR increased by 13%, although this was not statistically significant. Group B was 25 medium and heavy trucks from two distribution companies fitted with ADRs and matched with 188 trucks from the same companies and 76 from other companies that were not fitted with an ADR. Accident rates for vehicles fitted with an ADR reduced by 17%, although this	

				speed, rapid acceleration & decelerations, fuel consumption as well as driving speeds over the last 90 seconds before the vehicle stopped. The experimental field trial was aimed at assessing the effect of 'behavioural feedback' using data recorders. In this study, the methods of providing feedback was not specifically investigated (fleet owners cooperating in the study agreed to give feedback to their drivers).		of which were fitted with monitoring devices were involved in 1,836 road accidents.	was not statistically significant. Group C was 25 coaches from three different fleets owned by a tour operator fitted with JDRs and matched with 50 coaches from another company that were not fitted with a JDR. Accident rates of the vehicles fitted with a JDR reduced by 42%, which was statistically significant. Group D was 54 taxis and vans fitted with ADRs and matched with 66 taxis and vans from another company not fitted with ADRs. The accident rates for the taxis and vans fitted with an ADR increased by 54%, although this was not statistically significant. Group E was 23 company cars from an insurance company fitted with ADRs and matched with 21 non-professional cars without ADRs used for work purposes in the same company. Accident rates for the cars fitted with and ADR reduced by 3%, although this was not statistically significant. Group F was 23 coaches of a tour operator fitted with ADRs and matched with 9 coaches without an ADR from the same company. The accident rates of the coaches fitted with an ADR reduced by a statistically significant 72%. Group G was 10 taxis operating in a large city fitted with ADRs and matched with 5 taxis without an ADR operating in the same city. Accident rates were not given in the report. OVERALL, when adjusting for confounding	

							factors, the accident rate for vehicles fitted with a monitoring device reduced by 20%. When compared to vehicles without ADRs in their own company, the overall accident reduction for ADR vehicles was 31%. When compared to vehicles without ADR in their matched external company, the overall accident reduction for ADR vehicles was 12%, not statistically significant.	
Hickman & Geller (2003)	Road (trucks)	US	The relative impact of a self-management for safety (SMS) process was evaluated at two short-haul trucking terminals.	Behavioural Self-Management: drivers are taught to consider their own at-risk driving behaviours, their antecedents (situations leading to them), and their consequences. Drivers are encouraged to objectively observe and measure their own behaviour, set goals for improvement, self-monitor their progress, and reward themselves for successes. In this study, participants in the Pre-behaviour group (n= 21) recorded their intentions to engage in specific safe versus at-risk driving behaviours before leaving the terminal, whereas participants in the Post-behaviour group (n= 12) recorded their actual safe versus at-risk driving	Yes	Within-subjects comparison of overspeeding and extreme braking events during the SMS intervention period	DURING the intervention, participants in the Pre-behaviour group reduced their mean percentage of time overspeeding by 30.4% and their mean frequency of extreme braking incidents by 63.9%. The Post-behaviour group reduced mean percentage of overspeeding with 19.3% and their mean frequency of extreme braking incidents by 49.4%.	

				behaviours after returning to the terminal. Each participant drove a truck equipped with an on-board computer-monitoring device that recorded overspeed and extreme braking.				
Levick et al. (2004)	Road	US	This trial took place in an urban/suburban Emergency Medical Services (EMS). An aftermarket onboard computer system was installed in 20 ambulances over a 24 month period. The environment in which this study was conducted was the Cetronia Ambulance Corps in Allentown Pennsylvania, covering a region including urban, suburban and small metropolitan region. The parameters monitored include: vehicle speed (against user-set limits - both hot & cold), hard acceleration/braking, cornering velocity and g-forces, use of emergency lights and sirens, use of front seat belts, turn	The in-vehicle monitoring device provided real-time auditory feedback to the driver with warning 'growls' when pre-set parameters were approached and penalty tones when they were exceeded. Penalty counts were recorded when drivers exceeded certain parameters and downloaded daily for analysis. Electronic reports were generated for the drivers and their managers.	Yes. The onboard computer system monitors a set of parameters every second and provides real-time auditory feedback to the driver. The parameters monitored include: vehicle speed (against user-set limits - both hot & cold), hard acceleration/braking, cornering velocity and g-forces, use of emergency lights and sirens, use of front seat belts, turn signals, parking brake and back up spotters. Each driver has an individual key "fob" which is a simple device to be keyed into a special contact lock on the vehicle dashboard at the time of vehicle ignition, identifying the driver of that vehicle. The computer system provides an audible real-time feedback to the driver, by a system of warning growls and then	This was a prospective study design. In phase I (5 months), data was captured but no auditory feedback was given to drivers and there was no driver identification. In Phase II (13 months) auditory feedback was given to drivers but without identification of drivers. In phase III (8 months) the system was fully operational with auditory feedback and driver identification.	In this trial, the 20 ambulances covered over 950,000 miles, during which overall driving performance improved dramatically from high rates of speed infringements and high rates of not using seat belts. The most dramatic improvement was the reduction in speeding penalty counts with a reduction from 14.94 penalties/mile in phase I to 0.00003 penalties/mile in phase III. Seat belt violations dropped from 4.72 violations per mile in phase 1 to 0.001 violations per mile in phase III and continued to be sustained thereafter	

			signals, parking brake and back up spotters.		penalty tones for when the pre-set parameters are approached and exceeded. The onboard computer records penalty counts when drivers exceed certain set parameters. The penalty count data recorded by the onboard computer for exceeding these parameters are stored on the onboard computer and downloaded automatically to a base station on a daily basis for analysis and detailed electronic reports are generated. Management tracks trends and individuals.			
Levick & Swanson (2005)	Road	US	A metropolitan Emergency Medical Services (EMS) group installed an in-vehicle monitoring device, monitoring speed, hard acceleration and braking, cornering, use of emergency lights and sirens, use of front seat belts, indicators and the hand brake in 36 ambulances.	The in-vehicle monitoring device provided real-time auditory feedback to the driver with warning 'growls' when pre-set parameters were approached and penalty tones when they were exceeded. Penalty counts were recorded when drivers exceeded certain parameters and downloaded daily for analysis. Electronic reports were generated for the drivers and their managers.	Yes. The onboard computer system monitors a set of parameters every second and provides real-time auditory feedback to the driver. The parameters monitored include: vehicle speed (against user-set limits - both hot & cold), hard acceleration/braking, cornering velocity and g-forces, use of emergency lights and sirens, use of front seat belts, turn signals, parking brake and back up spotters. Each driver has an	This was a prospective study design. In phase I (3 months) of the study, initial data was collected but no auditory feedback was given to the drivers and drivers were not identified. In Phase II (3months), auditory feedback was given to the drivers, but individual drivers were not identified. In Phase III (12 months) auditory	, which equals a 4,000 fold reduction in seat belt violations. There were 19 vehicle incidents in the whole of 2004 (the monitoring devices were not installed until November 2004), 11 in 2005 and no major vehicle crashes during the fully implemented phase of the study period. Savings in vehicle expenses amounted to almost quarter of a million dollars a year, and more than covered the cost of installing and using the monitoring devices. There were also cost savings from fewer crashes, decreased vehicle damage, reduced accident investigation costs and insurance savings.	

					individual key "fob" which is a simple device to be keyed into a special contact lock on the vehicle dashboard at the time of vehicle ignition, identifying the driver of that vehicle. The computer system provides an audible real-time feedback to the driver, by a system of warning growls and then penalty tones for when the pre-set parameters are approached and exceeded. The onboard computer records penalty counts when drivers exceed certain set parameters. The penalty count data recorded by the onboard computer for exceeding these parameters are stored on the onboard computer and downloaded automatically to a base station on a daily basis for analysis and detailed electronic reports are generated. Management tracks trends and individuals.	feedback was given to the drivers and drivers used electronic key fobs so the system could identify which driver was driving the ambulance.		
Salminen et al. (2008)	Road (trucks included)	Finland	Driver group discussion involving company electricians who drive cars and TRUCKS for work	Group discussions: drivers work together to discuss safety problems, identify solutions, make an action plan, and act. Discussions and resulting	Not clearly specified	Before-after study of 172 electricians, exposed to discussion group method. No control, but compared with	Large (72%) decrease in traffic accidents over 8-year follow-up period, despite no decrease in other work accidents. However, general traffic safety trends not accounted for. Cost-benefit	This information is taken from

				measures evolve in several sessions over several months. Company safety campaign: presentations, information, visible campaign logo etc.		a similar group (n= 179) receiving driver training.	analysis shows savings: also improvements in safety audit outcomes, up to 2 years following driver training.	Nævestad et al. (2018)
Murray et al. (2009)	Road		Descriptive case study detailing comprehensive , "holistic" 5-year occupational road safety program targeting drivers-for-work employed by large company Wolseley	Program of events with several structural and cultural elements (e.g. competition, handbooks, focus groups, health training, eye checks, safety climate, etc.) involving researchers in collaboration with transport industry and a champion in a health and safety role.	Not clearly specified	Study analyses effect of program on fleet audit results based on accident data from 7000 heating and plumbing distributor drivers (3000 vehicles).	Almost 2-fold reduction of third party collisions per vehicle, and ≥500k savings on uninsured cost recoveries. The target company perceives many benefits of the program (e.g. improved compliance, performance management) but lacks supportive data.	This information is taken from Nævestad et al. (2018)
Hickman & Hanowski (2011)	Road (trucks)	US	Carrier A was a LONG-HAUL CARRIER located in the Southeastern US that primarily delivered goods. A total of 50 drivers had an OBSM device installed in their trucks. Carrier B was a LOCAL/SHORT-HAUL CARRIER located in the North-western US that primarily delivered beverage and paper goods. A total of 50 drivers had an OBSM device installed in their trucks.	2.3.2.2. In-vehicle monitoring with information (feedback light on the OBSM device:) AND 3.3.2.1.1.1. Reflective observation: two-way communication (coach looks at video-recorded events together with driver): the detailed coaching protocol included: (1) thorough review of video event, (2) review of driver's previous safety-related events, (3) playing the video together with the driver during the meeting, (4) explanation of the coach his viewpoint, (5)	Yes, DriveCam. Two camera views (driver's face view and forward-facing view) together with three accelerometers (y-,x-, and z-axis) that triggered an event to be recorded. If the criterion was met or surpassed (e.g. greater than or equal to 0.5g the OBSM device saved 12s of video (8 seconds prior to the criterion being met or surpassed and 4s after). Events recorded were: hard cornering, hard braking, hard acceleration, collision,	In each company frequency of safety-related events were compared within-subjects i.e. baseline (4 weeks) vs. intervention (13 weeks). No control group.	Carrier A significantly reduced the mean rate of recorded safety-related events per 10,000 miles traveled from baseline to intervention by 37% and Carrier B significantly reduced the mean rate of recorded safety-related events per 10,000 miles traveled from baseline to intervention by 52,2%.	

				objective and positive discussion, (6) determination of follow-up steps, and (7) document the meeting.	and rough/uneven surface.			
Musicant et al. (2011)	Road		**The 'DAVID' case.** This was a single driver case. David worked as a technician in a large commercial fleet along with other technicians. His work involved driving to customer locations in order to install or repair communication equipment.	The fleet safety officer decided to equip all vehicles with an in-vehicle feedback and monitoring technology called Green-Box. The monitoring device was installed in David's car for 1,054 days from 13 September 2006 to 1 August 2009, during which he used the car on 877 days for 5,704 trips, 126,443 driving minutes. He committed 6,878 undesirable driving events during this period. Feedback was not provided during a baseline period of September to December 2006, but was provided from the beginning of 2007.	Yes, Green-Box. This is an advanced driver's assistance system (ADAS) designed to provide drivers with feedback on their driving behaviour. The Green-Box reports commonly used measures of speed, travel time, distance and location. It identifies in real-time undesirable driving events such as extreme braking and accelerating, sharp turning and sudden lane changing. The identification procedure implements pattern recognition algorithms over the speed and acceleration profiles and reports about the occurrence of these events in real-time. A web application supplies aggregated information about the occurrence of these driving events to drivers and safety officers.	A before-after study was applied to evaluate whether David's exposure to driving feedback had an effect on his behaviour.	David's driving improved over time. At the beginning of 2007, his event rate for an average trip was 1.293, but had reduced by a statistically significant 82% by the beginning of 2008. The rate for the average trip by the beginning of 2009 was -0.640 fewer than in 2008. As David was a company car driver, his behaviour during and outside working hours was compared. His event rate was 26% lower on weekends and 29% lower when driving in leisure time, possibly because his work-time driving was in more difficult conditions (e.g. more traffic and time pressures during work hours).	
Murray et al. (2012)	Road	Australia	Comprehensive 5-year attempt to improve road safety	Mix of cultural and structural elements, but improving safety culture	Not clear	Case-study type quantification of development of	100% compliance with risk assessment and improvement process. Reduction in insurance	This information is taken

			management through range of proactive, fleet manager, insurance and risk-led initiatives in drivers-for-work at Roche.	central. Key initiatives: driver risk assessment, monitoring and improvement; policy development and communication; process and outcome evaluation; continuous review and refinement of policies, processes, programs. Intervention targets fleet managers, drivers, risk managers, and those who train and recruit drivers.		various safety behaviour and outcome measures over time.	claims costs (56%), collision costs (55%), and claims per vehicle (down from 36 to 28%) from 2004 to 2009. But, no accounting external trends or effect of which measure contributed most.	from Nævestad et al. (2018)
Wallington et al. (2014)	Road	UK	Case-study of long-term, data-driven extensive program targeting road safety in British Telecommunications (BT) with a fleet of approximately 35.000 vehicles.	Risks and costs established, and subsequent process structured by occupational Haddon matrix, with risk analyses and mitigation based on occupational health and safety principles. Effects of control measures (e.g. managers responsible for 5 or more drivers participate in a fleet safety coaching workshop) are monitored, and the measures are evolved accordingly. Measures cover levels of management culture and leadership, journey management, people, vehicle and society/community.	Not clear	Case-study of long-term trends in collision numbers, rates and claims in British Telecom based on data from up to 95,000 workers. Company traffic safety trend compared to national trend.	The overall claim rate (per 1000 vehicles) per year decreased notably and gradually from program initiation in 2001-2012. Compared with the general downward trend in the number of killed or severely injured in collisions in GB in the same period.	This information is taken from Nævestad et al. (2018)

Goettee et al. (2015)	Road (trucks)	US	Federal Motor Carrier Safety Administration (FMCSA) initiate training of new transport companies in the US, intended to foster a safety culture based on research indicating that small entrant carriers were less safe than established ones.	Training/mentoring and testing carrier managers to improve understanding of applicable rules and regulations and improve company compliance. Authority also guides and supports on record-keeping activities.	Not clearly specified	Cross-sectional design using a test group and a matched control group. "dose-response" conducted from 2009 to 2013. N= 117 in the first period and 177 in the second period. Self-selection challenge as participation in test group was voluntary.	Carriers that took part in the program had better safety outcomes than those who did not. Improvements were identified in the number of safety audit failures, roadside violations and crashes (up to 84% reduction).	This information is taken from Nævestad et al. (2018)
Naveh & Katz-Navon (2015)	Road (trucks included)	Israel	Intervention to improve organizational climate to improve road safety behaviour of drivers in diverse organisations, and their families.	Intervention designed and supported by the national road authority in Israel and carried out by designated teams at organizational "unit" level. Three-tier comprehensive multi-measure long-term intervention: (1) ISO-39,001 driven policy change and data-driven risk analyses, action plans (practices/procedures to address risks), manuals and trainings; (2) visibile management commitment and internal marketing supporting the policies (logos, tools, reward systems, road safety 'ceremonies'); (3)	Not clearly specified	Longitudinal before and after evaluation of intervention carried out by 51 "units" belonging to 11 organizations (selected from ca 50 volunteer organizations), including bus, truck, high-tech and administration companies. An additional company with 5 diverse units randomly selected as control group. Baseline survey of road safety climate administered 3 months prior to intervention, and 12	Average 75% reduction in traffic safety violations in intervention units, compared with an increase in control units. Increase in ratings of unit road safety climate in intervention units (decreased in control units). Multivariate statistical analyses and controls with manipulation checks, confirm the effects, and find that the reduction in violations is mediated by change in safety climate. Improvements spilled over to drivers' safe driving outside work, but not to family members' driving.	This information is taken from Nævestad et al. (2018)

				evaluations and continuous improvement.		months following start of intervention.		
Newnam & Oxley (2016)	Road	Australia	"Safety Management for the Occupational Driver" (SMOD) research-based program, focusing on manager's role in work-related road safety in a small-scale implementation case study.	Program focuses on four supervisory skills: motivation to improve driver safety (prosocial motivation), mindfulness (creating a safety climate where driver safety is prioritized and valued), role clarity and self-efficacy. Supervisors are trained in safety management of drivers, by teaching them to identify situations that pose increased risk to drivers, and effectively managing these situations. The program runs a monthly 3-4h sessions covering safety leadership styles, feedback from a 360-degree survey, role play and discussions. Supervisors implement the skills learnt from each session and are encouraged to monitor their own management behaviour.	Not clearly specified	Before-after study (n= 36) without a test group. Unfortunately, few (8) respondents answered the after study.	Improved safety climate. Improvements were also recorded on the four elements of the supervisory skills. However, low number of participants, especially in the after study.	This information is taken from Nævestad et al. (2018)
Camden et al. (2019-1)	Road (truck)	US	They conducted a needs assessment on what is needed to improve safety performance. Thereafter they implemented	An advanced safety program was implemented. Including a revision of the driver hiring policies, a proprietary driver-training program with the goal of	Yes, they equipped the fleet with: - automatic emergency braking systems. - lane departure warning - blind spot warning	Case-study over 6 years of long term trends in: - Federal Motor Carrier Safety	- 19.5% reduction in FMCSA-reportable crash rate - 20 percentile improvement in CSA Crash Indicator BASIC - 56% reduction in preventable, rear-end collisions	This information is taken from Camden et al. (2019)

			interventions to improve the fleet safety.	improving safety and creating a consistent safety expectation and message for all drivers across all commodities, hiring full-time driver trainers to deliver all-in persons trainings, installing new technologies.	- video-based onboard safety monitoring	Administration-reportable crashes, - Compliance, Safety, Accountability Crash Indicator Behaviour Analysis and Safety Improvement Category - Preventable, rear-end collisions.		
Camden et al. (2019-2)	Road (truck)	US	They conducted a needs assessment and interviews on what is needed to improve safety performance. Thereafter they implemented interventions to improve the fleet safety.	An advanced safety program was implemented. Including a revision of the driver hiring policies (hiring newly licensed commercial driver's license drivers), a buddy project where new drivers were paired with a driver trainer, an improved safety pledge, introduction of driver scorecards, implementing an improved safety culture, installing new technologies.	Yes, they equipped the fleet with: - onboard safety monitoring - lane departure warning	Case-study over 1 years of trends in: - Federal Motor Carrier Safety Administration-reportable crashes, - Compliance, Safety, Accountability Crash Indicator Behaviour Analysis and Safety Improvement Category - Compliance, Safety, Accountability Unsafe Driving Behaviour Analysis and Safety Improvement Category	- 7% reduction in FMCSA-reportable crash rate - 70 percentile improvement in CSA Crash Indicator BASIC - 49 percentile improvement in CSA Unsafe Driving BASIC	This information is taken from Camden et al. (2019)
Camden et al. (2019-3)	Road (truck)	US	They conducted a needs assessment and interviews on what is needed to	An advanced safety program was implemented. Including a new hiring policy with	Yes, they equipped the fleet with:	Case-study over 5 years of trends in:	- 6% reduction in preventable crashes	This information is taken from

			improve safety performance. Thereafter they implemented interventions to improve the fleet safety.	specific criteria (no more than two overall speeding violations in the previous 12 months, no more than four preventable crashes in the previous 3 years, etc.), implementation of a driver finishing school, provision of biannual safety meetings for all drivers, making improvements in the safety culture, frequent safety communication, quarterly meetings with the fleet owner, safety bonuses, reducing the number of drivers under each driver manager, installing new technologies.	- automatic emergency breaking	- Preventable crashes - Compliance, Safety, Accountability Unsafe Driving Behaviour Analysis and Safety Improvement Category	- 17 percentile improvement in CSA Unsafe Driving BASIC	Camden et al. (2019)
Camden et al. (2019-4)	Road (truck)	US	They conducted a needs assessment and interviews on what is needed to improve safety performance. Thereafter they implemented interventions to improve the fleet safety.	An advanced safety program was implemented. Including completing an in-person safety training for al new hires, monthly retraining and refresher information to all drivers, annual safety reviews for each driver, training on hours-of-service regulations, buying new software to see driver's hours in real-time, changing the safety culture, 24/7 availability of dispatchers, investing in new equipment, a shorter replacements	Yes, they equipped the fleet with: - automatic emergency braking - lane departure warning - roll stability control - collision mitigation suite	Case study over 6 years of trends in: - Compliance, Safety, Accountability Unsafe Driving Behaviour Analysis and Safety Improvement Category - Compliance, Safety, Accountability Maintenance Behaviour Analysis and Safety Improvement Category	- 45 percentile improvement in CSA Unsafe Driving BASIC - 24 percentile improvement in CSA Maintenance BASIC - 70 percentile improvement in CSA HOS BASIC - Eliminated all preventable rear-end crashes and rollovers	This information is taken from Camden et al. (2019)

				cycle and implementing new technologies.		- Compliance, Safety, Accountability hours-of-service Behaviour Analysis and Safety Improvement Category - Preventable, Federal Motor Carrier Safety Administration-reportable crashes related to automatic emergency braking and roll stability control		
Camden et al. (2019-5)	Road (truck)	US	They conducted a needs assessment and interviews on what is needed to improve safety performance. Thereafter they implemented interventions to improve the fleet safety.	An advanced safety program was implemented. Including a new hiring strategy, extra training for drivers, making improvements on the safety culture, investing in the latest advanced safety technologies, extra training for the dispatchers, a new vehicle inspection protocol.	Yes, they equipped the fleet with: - video-based onboard safety monitoring - speed limiters - automatic emergency braking - adaptive cruise control - collision mitigation system	Case study over 6 years of trends in: - Preventable, Federal Motor Carrier Safety Administration-reportable crashes	- 8% reduction in FMCSA-reportable crashes (10% reduction in 2018 alone)	This information is taken from Camden et al. (2019)
Camden et al. (2019-6)	Road (truck)	US	They conducted a needs assessment and interviews on what is needed to improve safety performance. Thereafter they	An advanced safety program was implemented. Including a new hiring policy with strict criteria, one-on-one meetings with the Safety Supervisor to review	Not clearly specified	Case study over 2 years of trends in: - Federal Motor Carrier Safety Administration	- 66.3% reduction in FMCSA-reportable crash rate - 44 percentile improvement in CSA Crash Indicator BASIC	This information is taken from Camden et al. (2019)

			implemented interventions to improve the fleet safety.	company safety policies, each quarter a training for the drivers, process for peer-observation and safety reporting, regular ride-alongs with drivers.		reportable crash rate - Compliance, Safety, Accountability Crash Indicator Behaviour Analysis and Safety Improvement Category		
Camden et al. (2019-7)	Road (truck)	US	They conducted a needs assessment and interviews on what is needed to improve safety performance. Thereafter they implemented interventions to improve the fleet safety.	An advanced safety program was implemented. Including a renewed hiring policy, implementing, several driver training programs, an improved, more friendly community within the organization, installing new technologies.	Yes, they equipped the fleet with: - video-based onboard safety monitoring - speed limiters - automatic emergency braking	Case study over 2 years of trends in: - Federal Motor Carrier Safety Administration reportable crashes - Compliance, Safety, Accountability Crash Indicator Behaviour Analysis and Safety Improvement Category	- 26.3% reduction in FMCSA-reportable crashes since 2012 - 66.3% reduction in FMCSA-reportable crash rate from 2017 to 2018 - 38 percentile improvement in CSA Crash Indicator BASIC since 2016	This information is taken from Camden et al. (2019)
Camden et al. (2019-8)	Road (truck)	US	They conducted a needs assessment and interviews on what is needed to improve safety performance. Thereafter they implemented interventions to improve the fleet safety.	An advanced safety program was implemented. Including a renewed hiring procedure, extra on-the-job trainings, quarterly trainings conducted by the Director of Safety, use of online training modules, opening of a new terminal to increase regional routes.	Not clearly specified.	Case study over 4 years of trends in: - Federal Motor Carrier Safety Administration reportable crashes - Compliance, Safety, Accountability Crash Indicator Behaviour Analysis and Safety	- 24.4% reduction in FMCSA-reportable crash rate - 39.7 percentile improvement in CSA Crash Indicator BASIC since 2014	This information is taken from Camden et al. (2019)

						Improvement Category		
Camden et al. (2019-9)	Road (truck)	US	They conducted a needs assessment and interviews on what is needed to improve safety performance. Thereafter they implemented interventions to improve the fleet safety.	An advanced safety program was implemented. Including implementing new driver training programs, biannual safety meetings, face-to-face coaching, scheduling weekly home time and installing new technology.	Yes, they equipped the fleet with: - video-based onboard safety monitoring	Case study over 2 years of trends in: - all incidents - Federal Motor Carrier Safety Administration reportable crashes - Compliance, Safety, Accountability hours-of-service Behaviour Analysis and Safety Improvement Category	- 53.6% reduction in all incidents - Zero FMCSA-reportable crashes - 46 percentile improvement in CSA HOS BASIC score	This information is taken from Camden et al. (2019)

Table 25: Field trials and case studies implementing interventions to promote occupational safety in aviation: based on Nævestad et al. (2018)

AIR TRANSPORT								
SOURCE	**TRANSPORT MODE**	**COUNTRY**	**CONEXT**	**INTERVENTION APPROACH**	**IVMS-COMPONENT INCLUDED?**	**EVALUATION DESIGN**	**IMPACT**	
Edkins (1998)	Aviation	Australia	Comprehensive program – INDICATE (Identifying Needed Defences In the Civil Aviation Transport Environment) – intended to improve safety performance in regional airlines.	Eight-month trial with 6 core activities: (1) appointment of operational safety manager responsible for training, coordination, evaluation and improvement; (2) proactive hazard identification by focus group with management; (3) confidential hazard reporting system; (4)	Not clear	Before and after 8-month trial with test group (N = 81) control group (N = 72). Quantitative and qualitative assessment.	- Improved safety culture. - Improved reporting rates. - Lower hazard perception. - More actions taken on identified hazards	This information is taken from Nævestad et al. (2018)

				regular safety meetings to address identified hazards; (5) safety information database allowing managers to monitor threats identified and actions taken; (6) internal safety marketing for visible management commitment.				
Boedig-heimer (2010)	Aviation	US	Pilot reliability certification intervention by expanding Crew Resource Management training in an air operator. Aim is to improve knowledge of and attitudes towards reducing human error in the cockpit.	Classroom or online training curriculum with six themes including resource management and personal error and awareness control.	Not clearly specified	Controlled, quasi-experimental survey evaluation of change in knowledge and attitudes towards human error in cockpit evaluated before and after implementation of the training, in pilots in treatment (n = 41) and control (n = 62) groups.	Significant improvement in safety attitudes and knowledge, but confounded by demographic differences between control and treatment group. Qualitative evaluation supports the result, and that treatment group more aware of minimal, yet critical lapses that may pass unnoticed	This information is taken from Nævestad et al. (2018)
Belland et al. (2010)	Aviation	US	Study of effect of increase in organizational safety commitment and support occurring from 1998 on, as result in ‘‘spike” of dangerous air incidents at US Navy air base	Visible change in management commitment to safety, achieved by routine personal message on safety and command culture from Naval air commander, culture workshops, safety surveys, increased focus on HFACS and pilot qualification.	Not clearly specified	Retrospective analysis of mishap rate 10 years before and 10 years after the intervention.	27% reduction in ‘‘Class A” mishaps per 100,000 flight hours in a single carrier air wing aviator group at treatment base cf. fleet control.	This information is taken from Nævestad et al. (2018)
Galazkow-ski et al. (2015)	Helicopter	Poland	Assesses effectiveness of a systemic training	Competencies trained by air instructors and simulator guidance.	Not clearly specified	Non-controlled prospective before-after study.	Overall decrease in contribution of human factors to incidents from before to after period, despite a rise	This information is taken

			program on human, technical and organizational competencies required on replacing an older ‘‘analog” HEMS fleet with new EC135 helicopters containing a high level of electronics and automation.	Training based on human technical, and organizational causes resulting from incident analysis of before period			in flight hours. However, increase in relative level of human errors registered, indicating an increase in threat levels. Effectiveness based on low numbers of incidents (e.g. 56 in before period), with large variation in level of contributory human factors from year to year.	from Nævestad et al. (2018)
Teperi et al. (2015)	Aviation	Finland	Aim to change safety culture in air traffic control by changing ‘‘managers’ understanding of human risks, strengths and opportunities”.	Learning from incidents restructured, using a checklist tool that guides controllers and managers to consider systemic causes of incidents. Training in checklist lasts up to one day, with several minutes required for each subsequent incident analysis.	Not clearly specified	Survey with open questions to assess user experience at 27 units using the tool.	Frequency at which individual characteristics are attributed as causal factors decreases with increased use of tool and understanding. No validation of tool in terms of effects on culture or safety.	This information is taken from Nævestad et al. (2018)

Table 26: Field trials and case studies implementing interventions to promote occupational safety in rail: based on Nævestad et al. (2018)

RAIL TRANSPORT								
SOURCE	**TRANSPORT MODE**	**COUNTRY**	**CONEXT**	**INTERVENTION APPROACH**	**IVMS-COMPONENT INCLUDED?**	**EVALUATION DESIGN**	**IMPACT**	
Zuschlag et al. (2016)	Rail	US	‘‘Clear Signal for Action” intervention implemented in Union Pacific Railroad, after observations of negative safety culture. Based on	Implemented by Behavioural Science Technology (BST) Inc., to introduce non-disciplinary, proactive, systems safety- analysis orientation, cooperative and sustainable. This	Not clearly specified	Before and after pilot study with two experiment units and three control units Study conducted 2005–2008. Safety culture measured	- 80% drop in at risk behaviours - 81% drop in accidents - Improved safety culture	This information is taken from Nævestad et al. (2018)

			safety culture theory of Reason (1997)	was done by peer-to-peer feedback, continuous improvement through cooperation at all levels, and safety leadership development.		quantitatively before (N = 195) and after (N = 112) and in qualitative interviews before, during and after (N = 53)		
Safe-2-Safer Amtrak (2015)	Rail	US	Safe-2-Safer program in large US rail company, aimed at improving company safety culture, reducing costs and injuries.	Improved safety leadership and peer-to-peer observation process.	Not clearly specified	Safety culture was measured by a biennial employee survey, focusing on 10 aspects of safety culture. Conducted from 2009 to 2013 (N = 11,700 in 2013)	Small improvement in safety culture, reduction in unsafe working conditions (through p-2-p observation), but increase in injuries	This information is taken from Nævestad et al. (2018)
Roberts et al. (2015)	Rail	US	Extensive program of measures to improve safety culture in New York City Transit Authority.	Baseline set and needs analysed with safety culture survey, increased inclusion of employee reps in accident investigations, multi-level cooperation at safety meetings, visible leadership and financial commitment, increased on-site inspections.	Not clearly specified	Two safety culture surveys in 2010 and 2013. Also focus on severe accidents, key statistics, employee views on safety and an FTA review.	Serious injuries appear to have declined. The second safety culture survey found improved reporting culture.	This information is taken from Nævestad et al. (2018)
Roberts et al. (2015)	Rail	US	Extensive program of measures to improve safety culture in Washington Metropolitan Area Transit Authority.	Safety prioritized in mission statements, increased investment in safety department, roles and responsibilities clarified, ‘‘lessons learned” bulletins, safety hotline, nonpunitive reporting.	Not clearly specified	Focus groups and safety culture survey in 2007 (N = 756). Safety culture problems were found in the survey and measures implemented. Number of fatal accidents used as a measure of improvement.	The intervention was found to reduce fatal accidents from three every two years before program initiation, to two over nine years after program initiation.	see Naevestad et al. (2018)

Table 27: Field trials and case studies implementing interventions to promote occupational safety in maritime: based on Nævestad et al. (2018)

MARITIME TRANSPORT								
SOURCE	**TRANSPORT MODE**	**COUNTRY**	**CONEXT**	**INTERVENTION APPROACH**	**IVMS-COMPONENT INCLUDED?**	**EVALUATION DESIGN**	**IMPACT**	
Lappalainen et al. (2014)	Maritime	Finland	Introduction of ISM (International Safety Management) code for international shipping, with requirement on safety management systems (SMS).	SMS requirements include proactive risk assessment, with assessment of risks, establishment of control measures, documentation of this, and a requirement for masters to ''periodically" review their vessel's SMS and report deficiencies to shore based management, Procedures for corrective action include measures to prevent recurrence, and annual mandatory internal safety audits.	Not clearly specified	(a) Literature review of previous studies of the ISM code, and (b) 94 interviews conducted with shipping companies, mariners and other maritime stakeholders in the Finnish shipping industry in 2008–2009	- Improved safety level - Improved safety culture	This information is taken from Nævestad et al. (2018)
Röttger et al. (2016)	Maritime	US	Officer training on Bridge Resource Management.	Training given to junior sea officers by officers experienced in Crew Resource Management for helicopters. Focus on leadership commitment, communication, coordination, performance under stress, decision making, situation awareness, attitudes and motivation that can lead to ineffective / unsafe	Not clearly specified	Prospective before/after evaluation of effect of training on knowledge, skills, attitudes, along with ratings of safety behaviour during real world exercises. Pseudo randomly assigned experimental group (n = 57) with control (n = 60) who receive nonrelevant safety training course. However, final statistical analysis only performed	Significant increase in knowledge on BRM only for experimental group, but no increase on other measures.	This information is taken from Nævestad et al. (2018)

				bridge resource management.		on 79 complete cases. No direct measure of effect of safety culture.		
O'Connor (2011)	Maritime	US	Officer training on Bridge Resource Management.	Similar to above, but less comprehensive. US Navy officers trained for 14h in the classroom, with 20h simulator training.	Not clearly specified	Change in knowledge, attitudes in response to training in 166 US Navy officers.	No significant changes.	This information is taken from Nævestad et al. (2018)

Conclusions for heavy vehicle fleet interventions with an IVMS-component

The current section focuses on a selection of the truck related safety intervention studies from Table 24 that included at least of the following three concepts: monitoring, feedback, and/or gamification. Importantly, feedback can be provided in different formats. We decided to ascribe the concept of feedback to a study in case they mentioned: feedback, coach(ing), school, and/or training/trainer. Similar, it is not clearly stated that studies purposefully included gamification as a method, rather, we based ourselves on the inclusion of keywords related to gamification, such as rewards. Of the 15 listed studies that included truck drivers, 13 were selected and summarized below with respect to the intervention approach, the inclusion of monitoring, and impact. Note that these interventions often contained additional components (e.g. strategic hiring strategies), which can contribute to the intervention results beyond the impact of monitoring, feedback, and gamification.

Feedback only (or monitoring not clearly specified)

- Camden et al. (2019) conducted a series of nine interventions to improve fleet safety in trucks based on advanced safety programs. The sixth program (Camden et al. 2019-6) included an updated hiring policy, one-to one safety supervisor meetings for reviewing company safety policy, quarterly driver training, peer observation and safety reporting, and ride-alongs with the drivers. The results of this program indicated a reduction of 66.3% in reportable crashes and a 44 percentile improvement in the CSA/BASIC crash indicator.

- The eightest intervention program from Camden et al. (2019-8) included a new hiring procedure, additional on-the-job training, quarterly training by the safety director, online training modules, and a new terminal to increase regional routes. They found a 24.4% reduction in the reportable crashes and a 39.7 percentile improvement in the CSA/BASIC crash indicator since 2014.

Feedback and gamification

- Naveh & Katz-Navon (2015) designed an intervention for truck drivers that included a multi-measure long-term intervention in three tiers: 1) policy change, risk analyses, action plans; manuals and trainings; 2) management commitment and internal marketing (e.g. reward systems); 3) evaluation and continuous improvement. Results showed that violations were reduced by 75% in the interventions units, while they increased in the control units. Moreover, ratings of the road safety climate in the intervention units increased, while it decreased in the control units. The reduction in violations was mediated by the change in safety climate. The improvements caused a spill-over effect to safe driving outside of the working hours, but not to the driver's family members.

Monitoring and feedback

- Wouters & Bos (2000) targeted road transport with trucks included. Their intervention contained two types of recording devices. A recorder for accident data (ADR), which collects data just preceding and during an incident or accident. The other recorder collected journey data, for instance, time schedules, mean speed, and fuel consumption. Drivers were informed that the devices were meant to help them adapt their driving behavior. To this end, feedback was provided to the driver, although the methods of providing the feedback were not investigated. The effect of the intervention depended on the groups that were included (i.e. containing different modes such as medium and heavy trucks, taxis and vans, etc.). Overall, accident rates for vehicles fitted with a monitoring device were reduced by 20%. If compared between vehicles with and without an ADR within company, accident rates for ADR vehicles reduces by 31%. If compared with external companies, accident rates for ADR vehicles reduced by 12%, although this was not significant. For trucks specifically, the findings were mixed, with one group (heavy trucks) showing that accident rates for ADR vehicles, when compared with another company, increased by 13% (although not significant). For another group (medium and heavy trucks) in two different companies, compared both within and between companies, accident rates for ADR vehicles reduced by 17% (again not significant).

- Hickman & Hanowski (2011) focused on truck drivers in an intervention containing both in-vehicle monitoring and feedback. Monitoring was both based on an OBSM device and a DriveCAM. The DriveCAM included two viewpoints, driver's face view and forward facing view. This was combined with three accelerometers, triggering any to-be-recorded events related to: hard cornering, hard braking, hard acceleration, collisions, and rough surface. Feedback was provided in real-time by a feedback light on the OBSM and post-trip. The latter contained reflective observation and contained two-way communication between driver and coach based on the recorded events. Included in the communication were, for instance, review of the event, coach viewpoint of the event, and objective/positive discussion. Two carrier types were targeted, long-haul and local/short-haul, and both showed improved driving performance. Long-haul reduced the recorded rate of safety-related events by 37%, while local/short-haul reduced this rate by 52.2%.

- The second truck intervention study from Camden et al. (2019-2) again included multiple components: revision of hiring policies, buddy project to pair new drivers with a trainer, improved safety pledge, driver scorecards, improved safety culture implementation, and installing technology (i.e. on-board safety monitoring and lane departure warning). The results showed a 7% reduction in reported crashes, together with a 70 percentile improvement in the CSA/BASIC crash indicator, and a 49 percentile improvement in the CSA/BASIC unsafe driving indicator.

- The first safety program from Camden et al. (2019-1) included several strategies, among which a revision of hiring policies, driver training program to improve safety and consistent safety expectations and messages, fulltime driver trainers for in-person trainings, and installing technology. They also provided: automatic emergency braking, lane departure and blind spot warnings, and video-based on-board monitoring. Results showed a 19.5% reduction in reported crashes, together with a 20 percentile improvement in the CSA (Compliance, Safety, Accountability) crash indicator score BASIC (Behavior Analysis and Safety Improvement Category), and a reduction of 56% in the preventable rear-end collisions.

- The components of the fourth truck intervention study from Camden et al. (2019-4) included: in-person safety training for newly hired, monthly retraining and refresher information for drivers, annual safety reviews for each driver, hours-of-service regulation training, software for driving hour indications, safety culture change, dispatchers available 24/7, new equipment investments, shorter replacement cycles, and installing technology. The fleet equipment included: automatic emergency braking, lane departure warning, roll stability control, and collision mitigation suite. The results indicated a 45 percentile improvement in the CSA/BASIC unsafe driving indicator, a 24 percentile improvement in the CSA/BASIC maintenance indicator, and a 70 percentile improvement in the CSA/BASIC hours-of-service indicator. Moreover, preventable rear-end crashes and rollovers were all eliminated.

- The fifth safety program from Camden et al. (2019-5) included: a new of hiring strategy, extra driver training, safety culture improvements, investments in the latest advance safety technology, extra dispatcher training, and a renewed vehicle inspection protocol. The fleet was equipped with: on-board video-based safety monitoring, speed limiters, automatic emergency braking, adaptive cruise control, and a collision mitigation system. An 8% reduction in reported crashes was found, with a 10% reduction in 2018 alone.

- The included components in the seventh intervention study by Camden et al. (2019-7) were: updated hiring policy, driver training programs, a more friendly community in the organization, and installing technologies. The fleet was equipped with: on-board video-based monitoring, speed limiters, and automatic emergency braking. They reported a 26.3% reduction in the reportable crashes since 2012 and a 66.3% reduction from 2017 to 2018. They also found a 38 percentile improvement in the CSA/BASIC crash indicator since 2016.

- The final ninth program by Camden et al. (2019-9) included driver training programs, face-to-face coaching, biannual safety meetings, weekly time home, and installing technology (i.e. on-board video-based monitoring). The results showed a 53.6% reduction in incidents, combined with zero reportable crashes, and a 46 percentile improvement in the CSA/BASIC hours-of-service indicator.

Monitoring and gamifcation

- Hickman & Geller (2003) focused on truck drivers in an intervention that included driver monitoring with an on-board computer device that recorded overspeeding and extreme braking. The intervention focused on ‘behavioral self-management’, indicating that drivers needed to reflect on their at-risk driving behavior, the antecedents and consequences. This means that drivers were responsible themselves for the intervention, for instance, by setting goals, observing and measuring own behavior, monitoring their progress and rewarding themselves in case of success. The intervention contained two groups and both groups improved their driving behavior. The group who recorded safety related intentions before they left the terminal reduced overspeeding by 30.4% and extreme braking by 63.9%. The group who recorded their actual safety behaviors on return to the terminal reduced overspeeding by 19.3% and extreme braking by 49.4%.

- The components from the third truck intervention study from Camden et al. (2019-3) included: revision of hiring policies, driver finishing school, biannual safety meeting for drivers, safety culture improvements, safety communication, quarterly fleet owner meetings, safety bonuses, reduced number of drivers for each manager, and installing technology (i.e. automatic emergency breaking). The results showed a reduction of 6% in preventable crashes, together with a 17 percentile improvement in the CSA/BASIC unsafe driving indicator.

The above summary can be further complemented with the components listed in the Haddon Matrix of successful safety improving strategies, as proposed by Camden et al. (2019), as shown in Table 23. This matrix describes pre-crash, crash, and post-crash factors in relation to the factors vehicle, people, environment, and management culture. In the intersection of these factors, strategies believed to be critical for improving safety outcomes are listed. For instance, a relevant strategy before a crash that relates to the driver is on-the-job training. The analysis made by Camden et al. (2019) combined with the information described earlier in this section teaches us that, indeed, the combination of monitoring and (gamified) feedback has been employed successfully in order to change safety culture in truck drivers. Important to keep in mind is that monitoring and (gamified) feedback are usually imbedded within a broader safety change intervention framework in which they are offered in combination with other strategies. For instance, including driver coaching and management commitment and support. Therefore, a focus on individual components will probably be insufficient to accomplish sufficient safety culture change.

Table 28: Haddon Matrix of successful safety improving strategies for heavy vehicle fleets as proposed by Camden et al., 2019

	Vehicle	People	Environment	Management Culture
Pre-crash	• Automatic emergency braking (AEB) • Lane departure warning (LDW) • Blind spot detection • Stability control systems • SpeedGauge • Speed limiters • Video-based onboard safety monitoring (OSM) systems • Monitor wear and tear • Replace parts when issues arise • 24 hour a day maintenance shop • Service tractors before 10,000 miles • Service trailers every 30 days • Inspect truck and trailer each time it returns to facility • Load specific pre-trip checklists	• Participant in Federal Motor Carrier Safety Administration's (FMCSA) pre-employment screening program (PSP) • Require previous driving experience • On-the-job training for all drivers • Finishing program for new drivers • New hire mentoring • Face-to-face interview • Hiring criteria for involvement in previous crashes • Hiring criteria for previous citations and inspections • Past employer referrals • Driver referrals • Driving simulator assessment • Driving simulator training • Online training • Hair drug testing • Physical fitness/agility test • Safety pledge • Monthly or quarterly in-person safety meetings • Coaching sessions based on OSM data	• Visible safety pledge signage in terminals • Plan routes for 45 mph average • Mandatory stops in bad weather • Schedule routes based on individual sleep patterns • Monitoring driving time in real-time	• Non-monetary safety awards • Monetary safety bonuses • Frequency safety communication • Positive, non-confrontational coaching sessions • Open door policy • Full-time trainers to maintain consistent safety message • Management buy-in to safety programs • Zero tolerance for HOS violations • Ownership/top management safety communication • Driver scorecards • Family events • Encourage family involvement in safety • Family culture • Progressive discipline policy • Internal and external safety benchmarking • Share key carrier-wide crash and incident data with drivers • Share carrier-wide safety cost data with drivers • Accountability for safety in all departments • Wellness checks on drivers • Educating all department on their impact on safety • Health and wellness program • Drivers collaborate to develop safety strategies
At scene				• Support driver at scene
Post-crash	• Vehicle repair or replacement	• Post-incident one-on-training • Progressive discipline policy based on crash causes • Health and wellness checks		• Use of video-based OSM to find identify objective data on crash causes • Use of video-based OSM data for driver exonerations • Internal tracking of crashes for data analysis • Internal and external benchmarking • Driver incident reporting system

E2.2. Overview of commercially available driver support systems

In this section, more specifically on the availability of already commercialized solutions concentrated that monitor driver behaviour of professional truck operators, and provide (persuasive) feedback, preferably in a pre- or post-trip setting, to promote a safe and/or eco-efficient driving style. More in detail, this section will be outlined as follows. First, an overview of products was included by Thijssen et al. in a paper on eco-driving among truck drivers that was published in 2014. More in particular, the authors listed up driver support systems that were aimed at improving eco-efficiency, based on a combination of on-board diagnostics and (persuasive) feedback provided in real-time and/or in a pre- or post-trip setting. In total, they were able to find 27 such products, and they summarized the most important functionalities in three consecutive tables (i.e. Table A.6, A.7, and A.8). These tables are shown into one overall table, and included it because it gives a nice and quite representative overview of what was available on the market at that point in time. The overview by Thijssen et al. (2014) however, was only a starting point for us. Almost six years have passed since this overview was published, so an update was necessary. Also, in their overview, Thijssen et al. (2014) focused not only on trucks but on cars as well. In fact, the majority of systems appearing in the list, were car-oriented instead of truck-oriented.

Therefore, a new search operation was conducted to identify and select existing systems, but with an exclusive focus on truck operators. 17 different systems were retained, all imed specifically at professional truck operators. In order to be able to conduct a functional analysis of these applications. First, a survey questionnaire was developed that was sent to the majority of the system fabricants. The more precise content of that survey and the administration procedure is summarized. Parallel to the survey questionnaire, all information collected (e.g. websites, technical documentation), and used that input to develop a series of technical descriptions. In addition to that, all the technical documentation we were able to retrieve, was subjected to a detailed content analysis, to find out as much as possible in terms ofthe parameters that were logged, the signal inputs used, the parameters for which feedback was provided, the feedback timing, and the gamification mechanics implemented.

Overview of eco-driving support systems by Thijssen et al.(2014)

In 2014, Thijssen et al. presented an overview of existing driving support systems to improve fuel efficiency. This overview included not only systems for trucks, but for cars as well. According to the authors, driver support systems can be subdivided into three categories:

- Systems that provide real-time feedback: these offer instant feedback on current operating conditions.
- Systems that provide short-term feedback: these provide feedback on a relatively short period of time which enables drivers to track their performance during driving.
- Systems that provide long-term feedback: these present feedback on longer periods of time which enables drivers to track their long-term progress.

  Table 29 gives the overview of the list of eco-driving support systems that was provide by Thijssen et al. (2014).

Table 29: Overview of eco-driving support systems for cars and trucks. Source: Thijssen et al. (2014)

Product name	Brand	Functionality	Website
CAMP2	HKS	CAN-bus reader and display, able to log fuel economy	http://www.hks-power.co.jp
DAF driver performance	DAF Trucks	Dashboard display: feedback on fuel consumption and driving style, provides tips for improvement	http://www.daf.com/newxf/en/index.html
Driving style evaluation	Iveco	Evaluation of driving style, and tips for reducing fuel consumption. Tips relate mostly to use of gearbox and brakes, acceleration and deceleration. Driver performance data is sent to fleet manager. System also comes with shift advisor	http://web.iveco.com/uk/Products/Pages/stralis-hi-way-driving-styleevaluation. aspx
Eco:Drive	Fiat	Data logging on USB-stick. Analysis, personal feedback, and corresponding lessons on computer	http://www.fiat.co.uk/ecodrive
Eco assist	Honda	Throttle/brake feedback, instantaneous feedback with color, long-term feedback with symbols	http://automobiles.honda.com/insight-hybrid/fuel-efficiency.aspx
Eco drive indicator	Hyundai	Gear change indicator	http://www.hyundai.com.uk/about-us/environment/blue-drive
Evo driving system	Kia	Color of dashboard symbol indicates real-time ecodriving performance	http://kia-buzz.com/eco-driving-system/
Eco pedal	Nissan	Active accelerator pedal: pushes during excessive acceleration. ECO-indicator on the dashboard supports the system	http://www.nissan-global.com/EN/TECHNOLOGY/OVERVIEW/eco_pedal.html
Eco trainer	Audi	Display gives information about fuel consuming accessories. A colored aura provides general efficiency feedback	http://www.popularmechanics.com/cars/news/4225312
Ecometer	Autometer	Instantaneous/average MPG gauge	http://www.autometer.com/ecometer/
Econav	Vexia	Navigation device that provides optimal gear information and gives feedback on braking and acceleration behavior. Monthly reports for progress tracking	http://www.vexia.co.uk/eco-tech
Economy tree	Nissan	Short term feedback based on: accelerator pedal, brake pedal, idling time, and, heater and airconditioner usage. Also long-term tracking	http://www.nissan.nl/NL/nl/vehicles/electric-vehicles/leaf/discover/3D/explore/ ecodrive.html#vehicles/electricvehicles/leaf/leaf-engine/explore/ecodrive/photos
Fleetboard	Daimler	Fleet management system for fleet owners. Information on driving style: speed, acceleration/braking behavior, gear selection, idle consumption, cruise control usage	http://www.fleetboard.com/info/en/vehicle-management.html
Fueless (smartphone app)	Het nieuwe rijden	GPS based app. Auditory shift advice. Feedback on eco-score, fuel consumption, acceleration, deceleration and speed	http://www.fleetboard.com/info/en/vehicle-management.html
greenMeter	Hunter	Provides general eco-scores. Provides information about e.g. relation speed - fuel consumption	http://hunter.pairsite.com/greenmeter/
Kiwi	PLX Devices	Shows fuel consumption and/or scores on four categories: smoothness, drag, acceleration and deceleration. Lessons are available	http://www.plxdevices.com/
Optifuel infomax	Renault	Fleet management software. Fuel consumption registration	http://optifuel.renault-trucks.com/en/manage-optifuel-infomax-presentation/
Prius interface	Toyota	Bar showing eco-value dependent on level of acceleration/deceleration. Shows fuel consumption histograms	http://www.toyota.nl/cars/new_cars/prius/index.tmex

REV (smartphone app)	DevToaster	Connects to CAN-bus and is, amongst others, able to log fuel consumption data	http://www.devtoaster.com/products/rev/
Road Trip (smartphone app)	Darrensoft	This application keeps track of long-tern fuel consumption and expenses by means of manual data entry	http://darrensoft.ca/roadtrip/
Scangauge	Linear-Logic	Instantaneous/average MPG gauge on numerical display, including short history graph	http://www.scangauge.com/
Driver support	Scania	Real-time support system which gives visual feedback and hints on the following aspects: hill-driving; anticipation; brake use; and, choice of gears	http://www.scania.com/products-services/trucks/safety-driver-support/driver-supportsystems/scania-driver-support/
SmartGauge	Ford	MPG gauge and a display showing growing leaves is short-term driving efficiency increases. Long-term efficiency is indicated by the amount of blossom flowers on the plant	http://www.ford.com/cars/fusion/
Torque (smartphone app)	Ian Hawkins	Vehicle diagnostics tool. Also capable of showing (average) mileage	http://torque-bhp.com/
Volvo board computer	Volvo	This display shows average and current fuel consumption, estimated consumption until destination, and, fuel consumption compared to earlier trips	http://www.volvotrucks.com/trucks/kuwait-market/en-kw/trucks/accessories/instruments/pages/fuel_economy_mode.aspx
Volvo performance guide	Volvo	Coach that helps the driver to operate the engine most fuel economically - including correct RPM, acceleration, and shifting	http://www.volvotrucks.com/SiteCollectionDocuments/VTNA_Tree/ILF/Business%20Tools/ Fuelwatch_Brochure_2008.pdf
Volvo dynafleet	Volvo	fleet management system offers detailed reports that make it easy to chart potential improvements and follow up the results	http://www.volvotrucks.com/TRUCKS/UK-MARKET/EN-GB/SERVICES/ TRANSPORT%20INFORMATION%20SYSTEM%20DYNAFLEET/Pages/dynafleet_online_main.aspx

Almost six years have passed since this overview was published, so an update is necessary. Also, in their overview, Thijssen et al. (2014) focused not only on trucks but on cars as well. In fact, the majority of systems appearing in the list, were car-oriented instead of truck-oriented. Therefore, we conducted a new search operation to identify and select existing systems, but with an exclusive focus on truck operators.

Questionnaire distribution and final selection

In order to execute a functional analysis of the TRUCK-specific systems, the following questionnaire was developed and distributed to the respective system companies.

1. For which of the following aspects, does the system provide any kind of feedback or warning to the driver (while driving or in retrospect)?
   a. Driver health & safety: Preventing fatigue/Attention, distraction/Eating & drinking
   b. Vehicle control: Accelerating/Steering/Reversing/Gear shifting/Braking
   c. Planning & observing while driving: Regular mirror checks/What to watch out for when reversing/Safe right turns/Safe left turns/Adjusting to weather & road conditions/Avoiding to get stuck in traffic/Defensive driving
   d. Sharing the road with others: Driving when angry/Signalling your intentions/Lane discipline/Overtaking & being overtaken/Traffic lights/Stop signs/Right-of-way/Safe distance in front

   e. Speed management: Exceeding speed limit/Adequate speed for circumstances/Indication of speed limits/Manage following distance
   f. Use of safety devices: Seat belt use/Parking Brake
   g. Eco-driving – anticipation, braking: Coasting time/Average brake counter/Average stop counter/Declaration/Within Economy time/Above Economy time/Top gear time/Engine load time/Engine overrev time/I-shift in Automatic time/I-shift in Manual time/I-shift in Power time
   h. Eco-driving – speed management: Average speed/Time above speed limit/Cruise Control time/Acceleration
   i. Eco-driving – stationary: Idling time
   j. Further features?
2. Which indicators are used for this purpose?
3. Where is the signal from the indicator taken from?
4. Does the driver receive real-time alert or feedback?
5. Does the driver get feedback in retrospect?
6. If in retrospect, when is it presented?
7. Is the improvement of this factor encouraged by some sort of gamification?
8. Which gamification method is used?
9. Is the improvement based on other behaviour change techniques? Which ones?
10. Further comments?

In order to execute a functional analysis of the TRUCK-specific systems, 19 system companies were contacted with the request to respond to a designed questionnaire (see Appendix A.x). Three systems were only identified after the questionnaire was distributed. One reminder was sent to all of the 19, while also trying additional contact options or alternative e-mail addresses found. A second reminder was sent to companies that indicated interest in the questionnaire, but did not reply after the first reminder. Of the 19 contacted companies, 6 replied to the questionnaire (i.e DKV Eco Driving, Dynafleet app, NEXT driver, Omnitracs, TX-ECO, and Vehco Mobile). After the questionnaire distribution, the analysis was started. During that time, the researchers updated the list of applications one last time since four systems were more applicable to other modes, compared to the truck mode (i.e. bus: BLED; car: DriveWell Fleet Program (CMT), GAFU, and VivaDrive). The final list contains the following 17 TRUCK-specific systems:

1. D2go
2. DAF Connect
3. DKV Eco Driving
4. Dynafleet app (Volvo Truck)
5. Fleetboard Driver.app (Roadstars by Mercedes Benz)
6. FleetGO®
7. Frotcom
8. IVECONNECT
9. NEXT driver (SD-Insights)
10. Omnitracs
11. Optifleet (Renault Trucks)
12. Scania Fleet Management
13. Truck Hero (Telematics from Route42)
14. Trimble Performance Portal
15. TX-ECO (Transics)
16. Vehco Mobile (Vehco®)
17. WaySmart® 820 (FAST DASH project

DAF Connect

DAF Connect is an application developed by DAF Trucks (Daf.Connect, 2019). The system that provides all the information for the platform of DAF Connect is available in all the new DAF trucks and it's possible to install a retrofit kit in older DAF trucks. It's possible to integrate DAF Connect into an existing fleet management system.

The on-board visual unit records the following parameters: fuel consumption, anticipation and braking behaviour, speed, route, location, distance covered, and driving time. These parameters are summarised into the a few reports: fuel report, ECO score card (individual driver score), vehicle health, alerts (on pre-set topics), and live fleet overview. The ECO score card helps the drivers to be more self-aware and motivated, because they can compare themselves to other drivers. DAF Connect claims to have some beneficial effects on the reduction of operational costs, increase of vehicle availability and achieving smarter maintenance. The result is lower fuel consumption, more customisation and a higher return per kilometre. It's possible to use DAF connect in Europe. The Dutch transport company Vonk & Co was one of the first users of the system.

D2go

Driver Challenge is an application developed by D2GO (D2go, 2019). The application works as an add-in for an application called Geotab Drive. Geotab's driver platform (Geotab Drive) streamlines ELD compliance, driver vehicle inspection reporting, driver identification, messaging, and provides options to do more. Drivers can easily record their Hours of Service (HOS) status and complete vehicle inspections from their tablet or smartphone.

The Driver Challenge tries to engage, motivate and coach the drivers of transport companies. By turning every day of driving into a friendly competition with a gamification solution. The transport company can choose the KPI's they are most interested in, by modifying the weight of the KPI's in the calculation of the total score. This way the transport company can chose for itself if it wants to focus on ecological driving, safety, productivity, etc. The drivers of the same transport companies can see each other's scores and ranking. Due to the immediate and continuous driver feedback it's possible for the driver to improve his/her score.

The application claims to have some beneficial effects on the drivers and managers. For the drivers the following benefits are identified: encourages friendly competition, raises awareness on the impacts of bad driving habits, and identifies and helps to avoid risky behaviour. For the managers the following benefits are identified: instant feedback that allows faster learning, better results with less coaching, and identifies risky drivers. The application is available in the United States and Canada. In December 2016 the application was used by a Canadian based carrier Transport Grayson.

NEXTdriver (SD-Insights)

NEXTdriver is an application developed by SD-insights (Nextdriver, 2019). NEXTdriver integrates the Fleet Management System from TomTom (WebFleet) and the Fleet Management System from Astra (FleetVisor). Due to this partnership there is no need to install special parts to the fleet. NEXTdriver focusses on the driving behaviour of the driver and tries to stand out through the continuous coaching of the drivers.

Drivers receive a report with personal advice each week. Via the application it's easy to contact the coaching experts, in case the driver has any recommendation or questions. The individual score of a driver will not be shown to the employer. The employer only gets a look at the progress of the whole group of drivers. In the application it's also possible for the drivers to receive rewards for achievements, challenge other drivers, and more. An example of a company that is using NEXTdriver is Jongeneel Transport. This is a transport company in the Netherlands. NEXTdriver claims to reduce fuel cost (5 – 10%), maintenance cost, damage repairs and safes time for the management, because management doesn't have to be bothered with the coaching of the drivers.

Scania Fleet Management

Scania Fleet Management Services (SFMS) is a set of services that connects the vehicles with the office (Scania Fleet Management, 2019). The goal of SFMS is to identify and use the details to increase productivity of the fleet. SFMS can be subdivided into three flexible packages: Monitoring, Control, and Data access.

The Monitoring package has two main features: a weekly summary of the vehicle, and a maintenance and needed repair planning. The weekly summary covers all vehicles of the fleet and is shown per vehicle (not per driver). The weekly summary has the following features: Scania driver support (average score), change in fuel consumption, CO_2-emission, coasting (driving with a gear engaged and without fuel injection is good driving behaviour), economical speed, idling, and heavy braking. The trend since last week is shown by red and green arrows. The Control package allows access to the application, the SFMS portal and all the information offered through the Monitoring package (and more frequent data reporting). The additional information that this package provides is: driver evaluation, vehicle evaluation, fuel report, event report, vehicle tracking, fleet position, environmental report, and a messaging service.

The driver evaluation checks the driver's driving style, so the transport company can help to improve driving to save fuel and reduce vehicle wear. The drivers are ranked by the greatest potential for improvement. The data access package enables the integration of data with other existing systems. The data will be in compliance with the remote FMS-standard. This is a good solution for operators with mixed fleets. All new vehicles of Scania are equipped with the necessary hardware. SFMS claims to reduce the operation cost of the operator.

Truck Hero (Telematics from Route42)

Route 42 is a company founded in 2015 and based in the Breda, Netherlands (Truck Hero, 2019). Route 42 tries to optimise four different aspects: the drivers' driving behaviour, fuel consumption, technical errors and accidents, and tire pressure. They provide five different kinds of solutions: Transport Intelligent Platform, Truck telematics, Trailer tracking, Vehicle tracking, and Reefer monitoring. The first two aspects are the most interesting for this project. The Transport Intelligent Platform is the Fleetbot^{beta}. Fleetbot^{beta} provides automatically the most important data to the right persons. The system is able to integrate the already existing logistical data sources, for example transport planning, existing FMS, external carriers, etc.

Truck telematics focusses on: drivers' driving behaviour (application Truck Hero), track and trace of the trucks, fuel consumption, unsafe situations (dashcam), remote diagnostics, remote download of the digital tachograph, waiting times, utilization of the trucks, and upcoming maintenance. The driving behaviour is measured on the following features: harsh breaking, harsh acceleration, excessive speed over a speed bump, hard cornering, rolling without the use of gas, and the use of cruise control. In the application Truck Hero, the driver gets personal coaching on the driving behaviour and how to improve the driving behaviour. The operator gets an overview of all the drivers' driving behaviour in a ranking. Due to the tracking of fuel consumption the operator is able to get an insight in the consumption of fuel and the possibilities to save on fuel costs. Examples of companies that are using Route 42 are Van den Heuvel, GVT Transport & Logistics, Lubbers Logistics, Verhoek Europe, etc.

Combination of real-time and post-trip feedback

DKV Eco Driving

DKV Eco Bundle is an application developed by DKV Euro Service and supported by TomTom, on the TomTom Bridge-devices (DKV Eco Driving, 2019). The product package combines the already existing application of DKV Eco Driving and the DKV Refuel Planning in the DKV Bonification system. The DKV Eco Driving works on telematics data: GPS-timestamp, GPS-speed, GPS-direction, vehicle status (on or off), driving time, distance covered, acceleration measurement, speed chart, etc. The DKV Refuel Planning holds the following information: shortest possible route and cheapest gas station. DKV Bonification tries to motivate the driver by a playful system to encourage economic driving behaviour. Drivers are scored by the DKV Eco Driving and DKV Refuel Planning applications. It's possible for the transport company to create user groups for the comparison between drivers. DKV Eco Bundle claims to reduce the fuel consumption by 5 to 10%, to reduce the fuel cost by 2 to 5% and to keep the drivers 100% motivated. It's possible to use the application in all the DKV countries.

Dynafleet app (Volvo Truck)

Dynafleet is a service developed by Volvo Trucks as a fleet management system (Dynafleet, 2019). Dynafleet exists out of four subservices: Dynafleet fuel and environment, Dynafleet driver times, Dynafleet positioning, and Messaging. Dynafleet fuel and environment present a fuel efficiency score to the driver and transport company. This score is calculated using four key variables: anticipating and braking, engine and gear utilisation, speed adaptation, and standstill. Dynafleet driver times present an overview of the most suited driver for a certain assignment based on the working hours. Dynafleet positioning uses real time updates on truck's speed, driver status, expected arrival time and more in order to choose the best suited truck for the assignment. Messaging keeps the driver and office up to date at all times. It's possible to use the screen in the truck for notifications on the remaining work time, slow traffic or best route to the destination.

The Dynafleet services work on several data sources: the truck's tachograph (driver card, memory and speed files), fuel consumption (fuel consumption, distance driven, emission levels), and positioning (GPS data, times, drivers, speed, load, vehicle type). In the updated version the drivers' behaviour is ranked based on a total fuel efficiency score. The drivers can track their own scores, as well as comparing their results with other drivers. In case a driver training is needed the transport company will be notified. Dynafleet claims to reduce the fuel consumption by up to 5%, improve the utilisation of vehicles and increase driver productivity.

Fleetboard Driver.app (Roadstars by Mercedes Benz)

Fleetboard Drivers is a platform (and application) developed by Daimler Fleetboard GmbH (est. 2003) and is a subsidiary of Daimler AG (Fleetboard, 2019). On the Fleetboard Drivers application the drivers can consult the different services Time Recording and Performance Analysis. The Time Recording services gives an overview of the driving and rest times of the drivers. It's also possible to view information on the start of shift, any rest time reductions and driving time extensions, the estimated remaining driving time, etc. all within the regulations. The Performance Analysis evaluates the driver using a grading system from 1 to 10. Independent of the degree of difficulty and the brands of the vehicles. The used information is fuel consumption, speed, stop times with the engine running, stops, etc. To be able to use the application it's necessary for the truck to be equipped with a digital tachograph and to be booked by central logistics office.

One of the most important data sources of this service is the digital tachograph. In the Performance Analysis a certain grade of gamification is noticeable. It's the goal to run the fleet more efficiently by scoring individual drivers (and coaching them): less wear and tear, less fuel consumption, and lower accident risk. Fleetboard Drivers claims to reduce the fuel consumption up to 15% and lower the CO_2 emission, reduce the cost associated with maintenance and repair services, and create a lower accident risk due to the constant checking of the defensive driving style of the drivers'. The application is available free of charge to drivers in 29 European countries as well as in Norway, Russia and Switzerland.

Frotcom

Frotcom is a fleet management tool for transportation companies (Frotcom, 2019). Next to the fleet management tools, the company also offers a lot of extra services or modules on their platform, one of them is a driver behaviour analysis. The driver behaviour analysis is based on over-revving, engine temperature, usage of cruise control, speeding, and over idling. The transport company is able to fine tune the end score by adding weights to the criteria. This driver behaviour analysis has no level of gamification. The drivers will receive a score. This allows the transport company to measure, reward and coach the drivers accordingly. The company focusses mainly on the savings on productivity and lower fuel consumption. Frotcom uses data from the digital tachograph and GPS in the vehicle. Frotcom is active all over the world. An example of a company that is using Frotcom is BION LOGISTICA Y TRANSPORTE a transport company based in Spain. Frotcom claims to lower the fuel costs by 7%, raise the productivity per day by 5.8%, increase the customer service, reduce the wear and tear, and reduce the accident risk up to 70%.

IVECONNECT

IVECONNECT is an exclusive system, for IVECO trucks, with an easy to use and integrated control system of the infotainment, navigation, driver assistance, and fleet services (Iveconnect, 2019). The system is developed by IVECO and Magneti Marelli. IVECONNECT can be subdivided in to two systems, IVECONNECT driver support and IVECONNECT fleet. The driver support part of IVECONNECT is equipped with a sat-nav truck navigation, a driving style evaluation, and a driver attention support function. The fleet management part serves as a tool for the fleet managers to enhance the efficiency. IVECONNECT driver support focusses on two topics that are interesting for the project: fuel savings and safety. The topic of fuel saving is covered by the driving style evaluation. The driving style evaluation processes information from the engine, the vehicle and the GPS in an advanced algorithm. The algorithm analyses the fuel savings performances of the driver. The system provides two types of feedback in real time: the evaluation of the driving style and also suggestions for reducing the fuel consumption. The topic of safety is covered by the driver attention support function. This function protects the driver against the risks associated with tiredness and sudden sleepiness. In case of drowsiness the system will give an acoustic and visual signal. IVECONNECT claims to reduce the fuel consumption by 5-12%.

Omnitracs

Omnitracs is a company that exists since 1988 and serves customers in more than 70 countries (Omnitracs, 2019). The company focuses on the development of software and applications for transportation companies to balance service quality, stability, and profitability while managing near-constant change. The aim of Omnitracs is to improve the productivity, reliability, safety and compliance of fleets. Omnitracs One offers many services and tools from basic GPS tracking to advanced routing, safety, and driver tools, you can fulfil any need on one advanced, easy-to-use platform. It's one single place that can be accessed from the mix of devices that works for the different parts of the fleet.

One part of the Omnitracs One platform is the Fleet Telematics. This is an on-board fleet tracking device (simple plug-in). That device will gather a multitude of data points: engine faults, idling time, speed levels and PTO. The transport company will get a clear picture of the fleet's risk level, productivity and maintenance status. With such comprehensive data, optimizing the fleet's performance, improving productivity, and minimizing maintenance costs can become a reality. Omnitracs also has a predictive risk mitigation analytics feature. This feature studies accident patterns, predicts future behaviour based off of patterns, and assign and reports risk-scores to drivers. This score is based on: time between jobs, training, license/certifications, type of experience, violations, etc. An example of a company that is using Omnitracs is H&M trucking. Omnitracs claims to reduce accident risk, reduce unnecessary costs like claims and legal fees, eliminate downtime and increase productivity, identify trends that drive up costs across the fleet, and monitor critical events and react proactively.

Trimble Performance Portal

Trimble has developed two interesting services Saving fuel together and Driver Safety, which can be consulted on the Performance Portal (Trimble Performance Portal, 2019). The Performance Portal will summaries al the FMS-data. Saving fuel together tries to maximise the drivers' performance. Idling, braking, acceleration, roll-out time, the use of cruise control, maintenance, etc. are all factors that have a direct impact on the cost of business. The operator can choose the weight of the KPI's, this way it's possible to focus on either safety or ecological driving. Within Save fuel together there are three modules: Truck performance, driver performance and company performance. Truck performance monitors the consumption evolution of a truck or a group of vehicles. Driver performance coaches the drivers towards an optimal driving style, by scoring every driver by a smart algorithm that takes the context into account of each trip. Company performance compares the scores and consumption of the entire fleet over different time periods. Each driver receives a Driver Scorecard (usually form the past month), with the spate scores and the different KPI's. This way it's easy for the drivers to compare their progress. Driver coaches also receive an overview of the performances of all the drivers (in colour code). This way the coach can educate the drivers on optimal driving behaviour.

Driver Safety is a solution combining in-vehicle hardware with a range of alerts, reports and dashboards about driver behaviour that can be utilized by managers and drivers to improve safety out on the road. By setting safety parameters and then scoring drivers against these, the transport company can identify those drivers who could be putting themselves and other road users at risk and offer training and advice to coach them to improve. Poor driving is also expensive driving; for those drivers over accelerating or speeding, they are wasting fuel needlessly and could be damaging the vehicle. The reports provided by Trimble Driver Safety help the transport company to see where a better driving style needs to be enforced to reduce fuel costs and minimize the impact on vehicle condition. Driver Safety leverages the GPS receiver in the in-vehicle hardware to collect the required data for analysis. Driver Safety tries to improve the safe-driving practices by: Sending audible and visual alerts to drivers when their actions are outside the set guidelines for aggressive driving; enabling driver-specific monitoring of speed, rapid acceleration and braking through the Driver Scorecard; and pinpointing vehicle location at a specific time to respond to unsafe driving complaints and traffic accident claims. The Driver Safety capability of the FieldMaster application allows visibility into the driving performance of individual and team members.

An example of a company that is using the services of Trimble is Ploeger Logistics, a company that is based in the Netherlands. Trimble claims to reduce accidents and improve employee safety out on the road, improve public image by promoting a safe driving culture, increase fuel savings through improved driving behaviour, improve productivity through better vehicle uptime, reduce operational cost by lowering fuel use and repair bills, and improve driver compliance using driver-style feedback.

TX-ECO (Transics)

TX-ECO is a brand-independent eco program, from Transics, that objectively evaluates and stimulates driver performance on economical and ecological driving (Transics, 2019). The program combines in-cabin driver tools, key performance indicators, alarms, driver scores and (trend) reporting. Its source is the truck's CAN bus data captured by the on-board computers. TX-ECO is fully integrated into the back office software TX-CONNECT. TX-ECO consists of 5 different eco modules, each with their own focus and impact: TX-ECO fuel, TX-ECO assistant, TX-ECO trip, TX-ECO performance, and TX-ECO monitor. However, the combination of several modules makes it possible to set up a professional and personalised eco project within the company. By combining the different eco modules, the company is not only able to chart the fleet's performance on various driving style parameters, but also identify “good” and “bad” drivers, follow up the results of a driver training, work on specific eco parameters and convince the drivers of their individual impact on fuel consumption and wear and tear.

TX-ECO fuel allows the operator to draft reports on fuel consumption and CO2 emissions by drivers and vehicles. With these reports, the operator has a basic insight into the key green parameters of the fleet. TX-ECO assistant on the on-board computer provides the drivers with a live overview and a daily score on the driving style based on four parameters: speed, number of revolutions, anticipation (braking) and idling. By gaining insight in the driving behaviour, drivers are motivated to sustain an optimal driving style. TX-ECO trip enables the drivers to compare the driving style parameters of the current trip to a reference trip. The data of both trips is presented next to each other in TX-CONNECT. TX-ECO performance is a universal evaluation tool that maps and evaluates driving behaviour to support driver trainers. It is based on those indicators that impact ecological and economical driving the most: idling, speed, RPM, cruising. Depending on their allocated weight, each of these partial scores affect the total eco assessment differently. TX-ECO monitor constantly captures driving behaviour data of each individual driver and sends it to TX-CONNECT at regular intervals. The different TX-ECO MONITOR reports visualise the following aspects of driving behaviour: idling, speed, coasting, cruising, anticipation, gearing, PTO (power take-off), RPM and engine load. TX-ECO claims to reduce the fuel consumption and CO_2-emission, increase driver, vehicle and cargo safety, lower the maintenance costs, and boost a green company image.

Vehco Mobile (Vehco®)

Vehco is a leading European provider of solutions for Fleet- and Transport Management, and part of AddSecure (Vehco, 2019). Vehco recognises that every company has its own unique needs, so it's possible to choose the most suitable solution. It's possible to choose the needed devices to use the Co-Driver services: Vehco Connect, Vehco Connect Light, Vehco Vision, Vehco Asset, and Vehco Mobile. Vehco Connect, Vehco Connect Light and Vehco Asset are all devices that are installed on the truck or trailer. Vehco Vision is installed in the cabin of the truck and is used together with Vehco Connect. For Vehco Mobile every driver can install Co-Driver on his/her own Android device (smartphone or tablet).

Depending on which devices are installed on the truck it's possible to enrol a list of services: positioning, eco-driving, checklist, qualified activities, navigation, messages, drivers' log, remote tacho download, drive- and resting times, route calculation, advanced social management, mission management, asset positioning, temperature monitoring, trailer coupling, and tacho analysis. The most important service in this list for the project is eco-driving. The eco-driving service analyses drivers' behaviour with objective indicators independent from the vehicle and road conditions. Linked to the CAN bus, the on-board computer in the vehicle collects reliable data (speeding, idling, braking, rollout, wasted energy, coasting) and transforms this data into relevant indicators. They are displayed on the driver's screen for real time coaching or on Co-Driver's weboffice for a complete analysis and follow up. Real-time in-cab display increases the drivers' awareness of the driving behaviour. Positive indicators are shown in green, and negative indicators are shown in red. The management is able to rank all the drivers and foster positive emulation between drivers. An example of a company that is using the services of Vehco is BC Catering Grossisten A/s, a company that is based in Denmark (Odense).

WaySmart® 820 (FAST DASH project)

Inthinc, a company based in Salt Lake City, has developed waySmart 820 Real Time Safety, RTS (Waysmart, 2019). The system is designed to create improvements in the driving behaviour of commercial fleet drivers. WaySmart 820 monitors the driver's driving habits such as speeding aggressive manoeuvres (i.e., hard accelerations and braking, severe turning, swerving, and hard bumps), and seatbelt usage through various sensors (measuring g-forces) and data from the vehicle's CAN bus. When the system detects that the driver is speeding, driving aggressively, or not wearing a seatbelt, it issues an in-cab, real-time **verbal and audible** feedback alert to the driver. If the driver fails to correct the behaviour, a violation is transmitted back to the company's designated reviewer (e.g., safety manager/driver manager).

The on-board monitoring system (OBMS) fleet manager portal provides summaries and detailed reports on driver and vehicle performance. The portal can be configured to view team summaries or detailed information on individuals. The summaries of past performance can be selected to cover the previous week, month, or year. Current tracking of vehicle units can be identified in real-time and shows location and status. Driver and team scores are calculated by an algorithm that increases the score penalties for higher severity events, such as speeding greater than 15 mi/h (24.1 km/h) above the posted speed limit or seatbelt not fastened at highway speeds. Inthinc claims that companies that employ the waySmart 820 RTS system achieve substantial savings in decreased accident and liability insurance, vehicle maintenance, and fuel costs.

E.3 Buses

E.3.1 Visual

Scania OptiMile and Fleet Management

Scania Fleet Management package is part of Scania OptiMile vehicle management service. The system is based on Scania's handheld computer and on-board communication module that monitors and stores a comprehensive set of vehicle data that can be accessed through a web-based logistics and telematics platform. Each vehicle and driver performance can be analysed and followed-up in great detail. Scania's open on-board IT-architecture and standardised protocol for fleet management systems makes the new systems compatible with other equipment on the market that is already in use with operators and with multiple OEM buses and coaches. The system also provides remote diagnosis and tachograph mass download services, as well as driver coaching. The driver coaching offers valuable insight into driver styles and efficiency, focusing on braking behaviour, efficient use of gear and continuous speed and speed fluctuations monitoring,

The interaction with both driver and fleet manager can is done through a web-based portal, a unified digital platform, named Scania One. Through it drivers can view assessments on their driving performance based on extensive comparison data from other drivers in their region of the world with similar driving assignments. Drivers can see their individual scores for key performance factors, graded A–E, with an overall aggregated score as the basis for improving skills. Likewise, operators can see how their drivers perform and plan targeted training activities.

GreenRoad BUS Telematics

GreenRoad BUS Telematics system lays on a couple of central cornerstones: engaging in-vehicle driver coaching and deep contextual safety insights and driver status monitoring. GreenRoad states that the theory underlying their system relies more on behavioural economics than engineering, according to which driving is a learned and habitual behaviour. However, although post-trip feedback is central to the solution, extensive reporting tools are available to fleet managers to follow up drivers' behaviour trends and, if necessary, provide the necessary post-trip feedback and training. Combining powerful and comprehensive analysis and KPIs with real-time feedback, GreenRoad bus and coach tracking telematics improve fleet utilization and operational efficiencies, enhancing asset reliability and reducing wear and tear, keeping track of service times, and monitoring health.

Similarly, to its competitors, the system has been evolving into a modular system with 4 axes: i) Driver Safety, ii) Operational Efficiency, iii) Compliance and iv) Performance consulting. Parallel to real-time feedback driver safety suite include extensive feedback and assistance features, namely:

- Safety Driving Scores - GreenRoad bus telematics not only provides, in-vehicle feedback, but it analyses and translates risky driving events into a simple, easy-to-understand, metrics for each driver and the entire fleet.
- Gamification strategies promote diver's engagement and motivates team members. By gamifying the process of driving, the system taps into employees' mental motivation

and rewards centres to create lasting engagement. Leveraging external rewards further enhances results, offering drivers even more incentive to engage.
- In-Vehicle video system captures footage of events that trigger safety warnings to give you deep insight into the root cause of risky driving behaviours. It helps fleet drivers and fleet managers uncover causes motivating unsafe driving events and provide evidence from critical seconds directly before, during, and after safety events.
- Event Hotspots and Route Hazards that Lead to Risky Driving - One of the best ways to make widespread change is to identify trends across your fleet. Whether it’s due to sharp turns or natural hazards, certain locations may stem driving situations riskier than others. GreenRoad’s fleet management hotspot tool lets you identify specific geographic regions where your fleet most frequently engages in specific unsafe driving behaviours.

Performance Consulting suite provide education resources and gamification strategies that help leveraging fleet managing programs and creating long lasting driver engagement. Similarly, to Fleetboard Driver Challenge, GreenRoad awards Fleet Elite status to drivers around the world who have demonstrated sustained excellence in driving performance and safety, inspiring drivers to act as models for their colleagues by providing them with an official recognition of achievement. Alternatively, GreenRoad also provides open API and SDK for third-parties to develop their tailored products, taking advantage of the systems proprietary vehicle sensing and safety algorithms, road awareness and driver related deep learning analytics.

Driveprofiler

Driveprofiler introduces a slightly different approach to telematics and driving feedback by extending classical analytic metrics. The Driver Rating Platform performs a driver risk scoring combining aggressive driving metrics, including harsh longitudinal and lateral accelerations and contextual overspeeding, with road type and layout classification, intersection count, excessive lane changing, time of day and week driving periods, and complementary data from external sources (e.g. weather pattern, claims and safety-critical events and hotspots).

Data collection can rely on nomadic devices (smartphones and tablets) for simplistic driving style assessment and risk assessment, OBD II or hardwired fleet management in-vehicle devices (MHUB 837, 846 and 855) connected to the vehicle CAN Bus networks for telematics and remote DTC fault code analysis, with additional external I/O ports for Driver Identification tags, temperature feeds and PTO monitoring. Using either inertial data alone or combined with vehicle data, Driveprofiler offers a Driver Feedback Software that can provide post-trip feedback to driver from embedded smartphone applications and web-based portal.

Jaltest Telematics

Jaltest Telematics from Cojali is an evolution of its original platform designed for maintenance and remote diagnosis for buses. The telematics and fleet management platform analyses driving behaviour based on key parameters, namely acceleration, braking, overreving, overspeeding, coasting, usage of primary and auxiliary braking systems, idle times, fuel consumption and/or other triggered customized alarms that can be defined by fleet managers. The feedback to driver relies on detailed reporting provided to fleet managers.

Pure Telematics

Pure Telematics is comprehensive bus and truck solution telematics and fleet management solution. The system provides to fleet managers a Driver Scoring tool that monitors and evaluates divers' behaviour and performance based on speeding, stop tracking, idling, acceleration patterns and fuel consumption data. Additionally, the system features frontal vídeo camera integration / dash cam that provides contextualization of driver performance behaviour and enables fleet managers to develop detailed, evidence based, driver feedback and training programs.

Stratio Automotive

Stratio Automotive started its business as predictive maintenance solution for buses and trucks, using data driven metrics and deep machine learning techniques. However, market demand has driven its product development into fuel efficiency and driver behaviour analysis. Leveraging on its CAN bus or FMS bus connection and inertial sensors, Stratio's Pilot service analysis both fuel efficiency and driver behaviour parameters, such as acceleration and braking patterns, speed engine, proper use of gearbox, coasting, etc. Since the tool is relatively recent, there are no advanced or autonomous driver feedback and engagement strategies.

FuelSave

FuelSave is a startup that was born from fleet managers will to take advantage of the high density of vehicle and driver data available on CAN and FMS buses. Presently, FuelSave is road trialling a coaching feedback and navigation dedicated for buses and trucks, however only advance driver analytics are availed in production units. The basic driver performance evaluation metrics are quite similar to the ones employed by Fleetboard. Currently driver feedback relies exclusively on fleet managers, but a driver app currently under development. The driver app will mostly mimic Fleetboard's features, namely providing post-trip autonomous feedback to drivers. However, the goal is not only to allow self-assessment at the end-of trip but also to allow drivers to compare their performance with both their fleet and drivers using similar vehicles and performing similar tasks.

E.4 Trains

Ćwil and Bartnik (2016) targeted train driving efficiency using gamification techniques. The gamification process included the use of points, badges, leaderboards, challenges and missions, systematic and direct feedback and inter group competition to try and influence behaviour. Self Determination Theory (SDT) was the behaviour change technique used to develop the intervention, aiming to alter employees' intrinsic motivation by ensuring the gamified elements adhered to influencing the three main psychological needs - autonomy, competence and relatedness. Autonomy was achieved through allowing resource acquisition for the employees' avatars, competence was adhered to through giving challenges, providing feedback and taking turns in the games (badges, leaderboards, levels and quests) and relatedness through allowing competition, co-operation, transactions and feedback (gifting, social graphs and teams). A Polish regional railway carrier implemented the game in separate parts sequentially across a 2-3 month period for each part. The first part was driver feedback, allowing drivers to check their energy use on a system as frequently as they liked. The second was comparison, with accurate information on energy saving given and challenges set, showing their performance compared to the average and giving rewards in the game for achieving set goals. Cooperation and group competition were then introduced in the third part with goals set for the team and the option to compete against other teams in amount of energy they could save. Finally, the social and mastery phase identified the best drivers and encouraged them to give help and tips to other drivers on how to improve. Unfortunately, the outcome of the study in terms of the apps ability to alter behaviour wasn't published, only the intended plan to be followed and the reasoning behind the application's design and development.

Bartnik and Ćwil (2017) expanded slightly on the above study aiming show the need for feedback to train drivers if there was a desire to reduce energy consumption. A two month 'placebo test' took place wherein the drivers were told their energy consumption would be monitored and recorded from the start of August, but in reality the collection of a baseline energy consumption figure had already started in July. It was found that energy consumption dropped by a significantly different amount in August compared to the July baseline but by September it didn't fall a significant amount further. This was taken as evidence by the authors that just informing that energy consumption would be monitored isn't enough for sustained improvements and therefore feedback, possibly through a gamified app, is of importance to see consistent energy reductions. Although the study didn't offer any post-trip feedback it was stated the purpose of the study was to find evidence of the need for such an intervention.

No further relevant studies were found for post-trip interventions. The above literature suggests such applications are feasible and of use in the rail industry but there is a clear scope for research to be published in this area in relation to energy efficiency, especially where an actual intervention took place. As of yet no post-trip interventions to improve railway drivers' safety appear to have been developed or tested in the current literature.