21st Century Trucking: A Trajectory for Ergonomics and Road Freight

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Abstract

Over the past decade there has been significant pressure to minimise emissions and safety risks related to commercial driving. This pressure to meet the triple bottom line of cost, environment, and society has often resulted in the rapid application of vehicle technologies designed to mitigate undesired effects. Often the cognitive and behavioural effects of technologies on the commercial driver have not received in-depth analysis to determine comprehensive viability. As such, this paper aims to identify a timescale for implementation for future technologies for UK road freight, and likely associated human factors issues, improving upon the currently employed 'trial-and-error' approach to implementation which may carry high economic, environmental, safety-related risk. Thought experiments are carried out to broadly explore these future systems. Furthermore, this work aims to examine whether technology alone will be enough to meet future CO_2 reduction targets, and assess the role of behavioural and systems interventions for future research.

Keywords: heavy goods vehicles, commercial vehicle drivers (CVD), roadmapping

1. Introduction

1.1. Triple Bottom Line

Over the past decade there has been significant pressure on the logistics industry to minimise emissions and safety risks related to commercial driving, augmented by the tension created by growing operational demands. Since the passage of the Climate Change Act of 2008, the UK Department of Energy and Climate Change has set the ambitious goal of reducing carbon emissions to 80% of reported 1990 levels by 2050. Department for Transport figures from 2009 reported that freight vehicles above 3.5 tonnes contributed to approximately 20% of all domestic transport carbon emissions and 4.2% of total national carbon emissions (Department for Transport, 2009a). Despite this, logistics activities are fundamental to economic growth and are on a trajectory to rise further with globalisation and consumer trends such as mass personalisation (AEA, 2012). This means the triple bottom line of cost, society, and environment have and will become increasingly difficult to achieve. Due to the UK's limited space, transport congestion and existing rail infrastructure, modal changes are unlikely to meet future needs and alternative manufacturing methods such as 3D printing have not yet reached a level of maturity which is suitable for mass adoption (McKinnon, et al, 2015). A great deal of existing logistics research has converged on system-level practices such as life cycle carbon accounting and integrated assessments to ensure that this triple bottom line is met, by considering the supply chain as a whole (e.g. Giminez, et al., 2012; Hacking & Guthrie, 2008; Rodrigues, et al., 2015; Schaltegger & Csutora, 2012). Systems approaches to these complex problems at the finest level of granularity are growing in use, and engineering interventions – particularly in vehicle design – also offer some attractive solutions. However, studies of human-technology interaction at the operational level are rare, despite the potential of designed technologies to support human behaviour throughout logistics activities (e.g. AEL, 2010). Logistics, therefore, is a fertile new ground for applied ergonomics with scope for significant impact. This paper attempts to demonstrate the role of human factors and technology design in future logistics systems to holistically assess the impact of carbon reduction measures in road freight, and to serve as a platform for future human factors work.

1.2. Moving forward from 'Hyper-Rationality'

Ergonomics is often the intervening variable between the expected benefits of technology and its actual outcomes, which can sometimes be substantially less than originally expected (Beekun, 1989). The roots of this paper are in localised end-user behaviour, particularly from the perspective of the commercial driving task. Road freight vehicles carry disproportionately significant carbon impact and safety risks in comparison to other transport modes; both of these are crucial points for which there exist considerable pressure to develop preventative technological solutions. As such, they are often trialled and quickly implemented without consideration of potentially substantial human factors issues such as the ability of people to reclaim control from automatic systems (e.g. Norman, 1990), the new and sometimes arbitrary tasks created (e.g. Bainbridge, 1986), behavioural and risk adaptation (Wilde, 1982), and the panoply of effects arising simply from all the unplanned adaptions people perform in order to make a new technology suit their own needs and preferences (Clegg, 2000).

The often rapid application of vehicle technologies designed to mitigate undesired effects and balance the triple bottom line means that the cognitive and behavioural aspects of the commercial driving task have been impacted. Disparities between actual versus expected outcomes seem to reside in a tacit theory of human behaviour: that within the logistics system humans are 'hyper-rational' (Croson, 2013). According to Croson et al. (2013), hyper-rational actors are characterised by the following:

1. they are motivated by self-interest in ultimately monetary terms;
2. they always operate in a conscious, deliberate manner; and
3. they behave optimally for a specified objective function.

Despite the growing acknowledgment of contextual human behaviour which defies this ‘hyper-rational’ characterisation – as evidenced by the recent increase in behavioural operations management literature (Bendoly, et al., 2009) – penetration of human factors research in the logistics sector is limited. The majority of human factors research in this domain has focused for a brief period of time on manufacturing activities – such as work published by the International Journal of Human Factors in Manufacturing – or otherwise on the physical ergonomics of assembly line work sub-systems (e.g. Bartholdi III, et al., 2010; Sundin, et al., 2004). Bendoly et al. (2009, p. 450) recommend that future work in behavioural operations management should centre on the question: ‘can this observed (though perhaps unanticipated) result be linked specifically to human behaviour? [...] Can we change the conceptualization of this effect from an ‘unanticipated’ one to one we can in fact expect?’ This trajectory speaks towards this high level aim and draws from established literature and industry insight to address it.

1.3. Profiling the Commercial Driver

The focus of the technology trajectory is the commercial driver, a relatively neglected human factors subject in comparison to the private car user (e.g. Quimby & Watts, 1982; Walker, et al., 2009; Young, et al., 2011). To provide a robust analysis of the effects of new technology a profile of the commercial driver end user was constructed from the academic literature. The commercial driver naturally spends more time behind the wheel in comparison to private vehicle drivers (up to 56 hours in any given work week) (European Directive (EC) 2003/88/EC, 2003), and the sustained mental workload associated with long-term tasks may cause performance to deteriorate (Lim, et al., 2010). It was found that (relative to private vehicle drivers) commercial vehicle drivers may exhibit stronger stress reactions to traffic conditions and commit more risky driving behaviours (Oz, et al., 2010), a factor which may compound itself in the time pressure which exists the industry. Commercial vehicle drivers (CVDs) may also exhibit heightened criticism of automation due to professional identity, exposure or familiarity with the traditional task, and some degree of technical knowledge of the current system (Donmez, et al., 2006), a finding which can be further supported by similar human factors research in air traffic control (Bekier, et al., 2012). Working consistently along familiar routes may foster inattentional blindness, which is of particular relevance to ensuring the safety of vulnerable road users (Yanko & Spalek, 2013). Naturalistic data also suggests that professional drivers have faster response times when performing an evasive manoeuver when compared to private vehicle drivers (Dozza, 2013). In terms of occupational health, long-term exposure to noise and vibration may affect the ability to engage with vehicle feedback (Majumder, et al., 2009). Quality of rest of CVDs may also be salient, as this affects attention as well as the potential for safety-critical incidents (Baulk & Fletcher, 2012; Bunn, et al., 2005; Darwent, et al., 2012; Hanowski, et al., 2007; McCartt, et al., 2000; Pirrera, et al., 2010). It is possible that further considerations may be necessary in technology design in order to accommodate the British CVD workforce which has a disproportionately increasing average age (Charlton, et al., 2013; Lees, et al., 2012; Llaneras, et al., 1998).

This characterisation of the CVD as an end user group, and an examination of the existing knowledge base as such, supports a platform for effective practical contributions to both research and practice in the logistics sector. Endeavours to meet the triple bottom line balancing economic, environmental, and safety benefits are currently operating under a complex set of industry constraints, in an extremely timesensitive sector. Attempts to meet the triple bottom line through isolated interventions suggest a sensitivity of the behaviour in the logistics system to a plethora of situational factors, which may hinder the radical changes necessary to meet carbon reduction targets (Ricardo AEA, 2012). This complexity necessitates a wider systems approach that considers not only future technology use, but the future task context in which operations will take place. This work is designed to take such a systems approach to holistically assess interventions which may, in reality, have minimal – or potentially even detrimental – environmental and safety-related effects, sometimes at considerable economic cost.

1.4. Technological Trajectory

In order to support a systems approach, the trajectory below will not only address technologies related to operational driving tasks but also technologies related to distribution and delivery tasks. This paper aims to outline future logistics technologies and their associated human factors. A survey involving a cross-section of major UK logistics companies was performed to gain insight into future real-world systems, by direct line of communication with key decision-makers developing and implementing commercial vehicle technology. Using a semi-structured interview format, technologies are identified by domain experts for potential implementation by 2020, 2025, 2030, and 2050. A framework for identifying appropriate human factors relevant to technologies in the commercial driving task is outlined and applied, based on past research in technology development and human-automation system performance. The degree of automation of each technology is reviewed to further link individual operational capabilities and behaviour with system design. Results support a more user-centred approach to meeting key logistics challenges, and a way to identify novel behavioural interventions.

Logistics technologies intended to reduce fuel costs, road accidents, and carbon emissions all hold the potential for unexpected and previously unstudied human-technology interactions, and this work aims to highlight where and of what types these interactions may be, as relevant to future system design. However, the primary focus of this initial work is to assess the impact of carbon reduction technologies set for implementation in commercial vehicles, in order to evaluate the progress toward government-set reduction targets and determine whether or not this goal can be achieved by technology alone.

2. Materials & Methods

2.1. Design

To provide the necessary insights into technology-induced impacts on the commercial driver a survey of leading logistics practitioners was performed. Industry-led insights were reflected by a systematic review of the knowledge base. The focus of the review was on commercial vehicle technologies intended to reduce greenhouse gas emissions, which enabled a technological trajectory to be developed featuring elements relevant to the commercial driving task. Although the focus of this work is on technologies designed to reduce carbon emissions, all technologies or systems issues identified by expert participants were included. Participants were selected from managerial roles and did not include the 'system users' (drivers) themselves, in order to first assess the efficacy of future systems on a broad level prior to delving into the specifics of usability. Ultimately, today's drivers have little say in the commercial vehicle technology with which they work daily – and the variation in existing vehicle design is vast. While this is undoubtedly a point for improvement in the design process for future systems, the objective of this study was to focus on the key decision-making point for technology adoption in order to track large-scale trends. This provided a hypothetical picture of future road freight transport systems and their evolution over time, which could be used as a point of reference for high-level human factors and carbon reduction assessments.

2.2. Literature Review

Academic journal search engines were used in initial searches for logistics technology information, followed by a targeted search of logistics, transportation, environmental interest, and human factors publications (e.g. Transportation Research; Annual Reviews in Control; Safety Science). This was supplemented by publicly-accessible web engine searches for technical documentation and statistical information from industry and relevant government bodies (e.g. Amsterdam Group; Department for Transport). Iterations of this process were carried out to ascertain the technical details, maturity, and affected user of each technology or trend. First-stage search terms were developed to detect technologies across logistics contexts, for example: heavy goods vehicle technology, intelligent transport systems, warehouse management systems technology, green logistics technology, logistics ICT, etc. Iteratively this was expanded as necessary to cover specific trends, technologies, vehicle types, and user characteristics as they occurred, for example: collision avoidance, logistics telematics devices, commercial driver fatigue, tachograph tampering, wireless sensor networks, etc. Attention was given to alternative terms, spelling variations, and acronyms, to ensure inclusion of specialised terms from each of the targeted subject areas.

2.3. Procedure

Relevant organisations were identified, and experienced specialists in managerial roles were selected and contacted from a wide range of industry sectors, including: logistics policy, infrastructure technology development and implementation, and key commercial activities with in-house distribution and/or third-party logistics (see Table 1). Key stakeholders from the UK logistics industry participated in the study. These included several major third-party logistics operators, international vehicle manufacturers, and UK government bodies. Semi-structured interviews were conducted in person or by telephone with 23 respondents. Open-ended interview questions were based around the following structure: What vehicle/warehouse/logistics transport technologies do you envision being implemented in the next 5 years; 10 years; 15 years; and beyond 15 years? Elaboration was encouraged where possible to maximise the specificity of general technologies or timelines. Salient trends were followed up with a question of the form: Could you elaborate on this trend/technology, and clarify when it is likely to be implemented in the logistics environment?

Table 1: Interview Participant Sample

LOGISTICS AREA	CATEGORY	JOB TITLE
INTERNAL LOGISTICS FLEET	Customer	Group Transport Manager
	Customer	Transport, Logistics & Warehouse Fleet Manager
	Customer	Senior Fleet Manager
WAREHOUSE	Intermediary	Consultancy Director
THIRD-PARTY LOGISTICS	Customer	Innovation & Efficiency Manager
	Customer	Technical Services Director
LOGISTICS/VEHICLE SPECIFICATION POLICY	Intermediary	Commercial Vehicle Development Manager
	Intermediary	Director of Policy
	Intermediary	Managing Director for Membership & Policy
	Customer	Road Strategy & Technology Lead
TECHNOLOGY RESEARCH & DEVELOPMENT	Intermediary	ITS Regional Director
	Supplier	Head of ITS Development
	Supplier	Principal Engineer

Supplier	Development Engineer
Supplier	Strategy & Business Development
Supplier	Advanced Engineering Program Manager
Supplier	Transport Solution Specialist
Supplier	Project Manager
Supplier	Chief Engineer - Chassis Strategies & Vehicle
Supplier	Vehicle Control & Analysis
Supplier	HMI Technology Project Manager
Supplier	Cognitive Engineer
Supplier	Specialist in HMI for Intelligent Vehicles

Technologies and timescales identified were documented as individual entries from each participant, along with applicable context (e.g. vehicle, infrastructure). Most technologies were identified consistently by multiple participants; however, where discrepancies were present, an average was taken and a standard deviation calculated to provide a range. Individual entries were synthesised into comparable categories as appropriate (e.g. both in-vehicle and portable telematics devices were categorised as 'Telematic Data Collection') supported by technical knowledge gained in the literature review.

2.4. Examination of Human Factors

From the literature review three central classes of technology were found, as described by Walker et al. (2001): transparent, opaque, and enabling. Technologies described as 'transparent' often relate to ubiquitous computing tasks which may be less directly apparent to the user, but which aim to optimise the fundamental links between vehicle and driver controls. The use of 'opaque' technologies may be more apparent to the end user, as these have a more detectable interface between vehicle and driver. Both transparent and opaque technologies have the potential to carry feedback which is minimally or highly obvious to the end user, with which they interact throughout performance of the task. 'Enabling' technologies create a framework for all technology, and support the congruence of vehicle technology components to improve overall mechanical and electrical efficiency. In this work, enabling items may also include basic design interventions such as aerodynamic fairings, or supporting systems technology such as natural gas infrastructure which is effectively tied to the 'range' of vehicles using natural gas fuels. Technologies identified by interview participants are described in terms of these categories.

The concept of Technology Readiness Level (TRL) played a key role in the development of the following human factors framework. TRLs are defined as measures used to assess the maturity of evolving technologies during their development, and in some cases during early operations, on a scale of 1 to 9. These scales are used internationally to track progress in technology development and determine when a novel technology is ready for widespread, real-world use. Recent reviews of the role of the TRL have noted that early and ongoing modelling of advanced technology at a contextual systems level will be a key challenge for future efficacy (Mankins, 2009). Reference was made to existing NASA/FAA guidance on TRLs to consider current practices for examination of human factors issues at each stage of technology development (Krois, et al., 2003). This provided a foundational outline of broad issues from which categories were selected, including: 'mental workload', 'situation awareness', 'allocation of function', and 'knowledge, skills and abilities'. These factors were narrowed to include only categories which were relevant to an immediate timescale, at a level of granularity which focuses only on the end user. Thus selected factors are tied directly to the operational behaviour of the end user in the immediate term, and not attached to broad considerations such as 'safety and health', team-level considerations such as 'communications and teamwork', or long-term considerations such as 'training'.

The remaining factors and knowledge of existing human factors themes gained from the literature review were used to develop three commonly recurring component-level attributes against which technologies could be broadly assessed for applicability: feedback, attention, and locus of control (Krois, et al., 2003; Walker, et al., 2015). As the goal of this examination is only to highlight potential issues as a platform for more detailed and contextual future research, attributes were chosen on the basis of being immediately essential to human-environment interactions in their most raw and simple form as required for adequate task performance. Attributes were selected to address what interactions are present in the system, and identify when these interactions are likely to occur, from a fundamentally operational perspective (as opposed to tactical or strategic considerations relating to less apparent cognitive processes, such as the effects of training on user adaptation to systems over time). This was intended to address requirements for the first and last stages of information processing, information acquisition and action implementation, at their most basic level in a way which can potentially be measured and related to system design. These attributes were:

Feedback – This attribute describes the extent to which the work system provides 'cues' to the end user enabling them to effectively perform their task in context – in this case, the task of delivery driving of a commercial vehicle. This feedback consists of three types of physiological signals received from the environment, including auditory signals such as engine noise or alarms; haptic signals such as vehicle handling 'feel' or vibrations; or visual signals such as speedometer readings or observation of other vehicles in the road environment. Not only is feedback essential to task performance for the direct user, but it is also essential for the surrounding agents within the environment to ascertain information about behaviour which may impact their own tasks. For example, pedestrians at a crossing may use visual cues or auditory feedback from approaching vehicles to gauge whether it is safe to cross. Technologies described as 'transparent' or 'opaque' carry feedback which is moderately or highly obvious to the end user, with which they interact throughout performance of the task.

Attention – Cognitive attention is required from the user to ensure that all is as expected throughout the task. This enables a natural process whereby the user 'supervises' the system as it responds to user-system interactions. This allows a comparison of real-time contextual behaviour to the user's expectations of system performance developed from training and experience, and is critical in prompting the identification of situations in which more engaged decision-making is required. The characteristics of attention, and the user's assessment of system behaviour, are also important elements in user adaptation to systems over time and, in turn, identifying emergent behavioural implications of system design.

Locus of control – From a systems perspective, any socio-technical work system has an allocation of function – a division of task responsibilities between human and technological actors. A human user's understanding of this distribution of task responsibilities is the individual's locus of control, and this perception of responsibility has influence on where and how the user's cognitive attention is directed to filter the overwhelming amount of feedback available in the environment. Recent research has characterised locus of control as a malleable contextual attribute affected by situational factors such as driver training, rather than a fixed personality trait, suggesting a connection to human-system interactions (Huang & Ford, 2012). In the case that the allocation of function and the locus of control are not complementary, issues for system performance may arise, and risk of system failure increases. While allocation of function may constitute a more objectively measurable attribute if systems analysis is already complete, a human user's locus of control provides an even more granular 'component' level attribute.

The applicability of the above attributes to each technology was evaluated with emphasis on the commercial driving task.

3. Results & Discussion

3.1. Trajectory of Technology

Each interview participant identified a technology and its likely time of implementation, and responses were logged in a master list to track the number of times each technology was identified, as well as the variability in perceived timescale to implementation. The trajectory for commercial vehicle technology use in the UK was constructed from these results, and was further classified by those technologies suggested to be in widespread or niche use. The review of industry and academic literature undertaken reflected this master list of technologies constructed from participant responses, and provided the relevant carbon reduction estimates as cited in Table 2.

Table 2: Classification, Description and Carbon Reduction Impact of Technologies Identified by Participants

GROUP	TECHNOLOGY	DESCRIPTION	PURPOSE	CO_2 REDUCTION PER HGV
TRANSPARENT TECHNOLOGIES	Automated Emergency Braking (AEB)	Automated emergency braking (AEB) detects nearby vehicles or objects and autonomously takes over control of the vehicle to slow or stop in the event of an imminent crash	Safety-related	
	Active Collision Avoidance Systems (CAS)	Active collision avoidance systems (CAS) employ automated emergency braking as well as trajectory control in the event that the surround sensor system detects an imminent crash with an oncoming or leading vehicle	Safety-related	
	Active Steering	Active steering adjusts the degree to which steering wheels contributes to wheel movement dependent on vehicle speed, such that manoeuvring in urban areas or small spaces at low speed is ergonomically optimised for the driver	Supports longer, heavier vehicles	
	Active Dolly Steering	Active dolly steering relies on advanced electronic control unit algorithms to enable large articulated vehicles to manoeuvre in roundabouts or otherwise tight spaces	Supports longer, heavier vehicles	
	Mild Hybrid Propulsion & Stop/Start Systems	This vehicle type is designed to be partially supported by electric propulsion, often with capability to automatically turn off the vehicle's engine after a short period of time at a stop in order to conserve fuel use	Applicable for medium duty urban vehicles and light duty vehicles only	
	Electric Hybrid, Battery Electric, Dedicated/Dual Fuel Gas, or Hydrogen Fuel Cell Propulsion	Each of these propulsion methods are supported by alternative fuels, which necessitate advanced control engineering, drive-by-wire systems, and regulation of the vehicle via the electronic control unit	Variable – not detailed due to uncertainty of uptake	
	Reduction of Rearward Amplification	The advanced development of control engineering to reduce rearward amplification is intended to increase stability, decrease the risk of rollover, and adjust vehicle dynamics for optimal fuel use for longer heavier vehicles	Supports longer, heavier vehicles	
OPAQUE TECHNOLOGIES	Topographical Adaptive Cruise Control (TACC)	Topographical adaptive cruise control autonomously adjusts vehicle speed based on the movement of surrounding vehicles, a set target speed, or a projection of upcoming gradient using GPS triangulation, or any combination	Reduces CO_2	2.0% - 6.0% (Baker, et al., 2009)
	Advanced Driver Assistance System (ADAS) Feedback	ADASs utilise vehicle dynamics data to provide warnings to the driver in safety-critical situations, and increasingly as feedback to improve eco-driving practice	Variable	
	Collision Warning Systems	Collision warning systems use surround sensor systems to detect nearby road objects to warn the driver of a projected collision	Safety-related	

	Haptic Interfaces	Haptic interfaces include touchscreen displays, vibratory seats or seatbelts, haptic pedals, haptic steering etc.	Variable	
	Next-Generation Digital Tachograph	Next-generation digital tachographs transmit vehicle dynamics and legally-required working hours data wirelessly to cloud storage, as opposed to the current method of data storage on integrated circuit cards carried by drivers	Safety-related	
	On-Board Safety Cameras	Safety cameras and in-cab displays make blind spots (thus surrounding road users) more visible to the driver, and are increasingly coupled with collision warning systems and/or ADAS feedback	Safety-related	
	Advanced Satellite Navigation & Routing Systems	Sophisticated satellite navigation systems will be customised to specific vehicle types for weight and dimensional data in order to avoid restricted routes (e.g. low bridges), and increasingly incorporate real-time traffic data	Variable	
	Infrastructure-to-Vehicle (I2V) Communications	Wireless communications (e.g. dedicated short-range communications) transmit local traffic condition information to each vehicle	Supports advanced routing	
	Head-Up Displays	Head-up displays present information on the windscreen in order to optimise attentional resources	Variable	
	Automated Low Speed Manoeuvring	Automated low speed manoeuvring utilises the surround sensor system to take autonomous control of the vehicle in order to make complicated reversals into loading bays or perform other low speed manoeuvres.	Supports longer, heavier vehicles	
	Heavy Goods Vehicle (HGV) Platooning	Platooning utilises surround sensor systems to facilitate vehicle-to-vehicle communication, appointing a lead vehicle in a 'road train' and enabling autonomous control of following vehicles at an optimal distance, minimising aerodynamic drag	Reduces CO_2	2.1% (Bergenheim, et al., 2012) - 20.0% (Ricardo AEA, 2009)
	Fatigue Detection Technology	Fatigue detection technology monitors the driver to recognise physiological signs of fatigue, and provides warnings to alert the driver, or triggers autonomous vehicle control to reduce the likelihood or severity of an incident	Safety-related	
ENABLING TECHNOLOGIES OR SYSTEMS/DESIGN INTERVENTIONS	Electrification of Hotel Loads	Electrification or alternative fuel use to support hotel loads (e.g. chilled trailers) in place of traditional fuel use	Supports alternative propulsion methods	
	Diesel-Mix Fuel Use	Additives which help to maintain the engine and advanced engine control strategies which support precise injection of diesel-petrol mix fuels improve efficiency	Reduces CO_2	Unknown for logistics vehicle use
	Heat Management	Heat management recovers and recycles engine heat to power a supporting turbine and generate energy	Reduces CO_2	3.0% - 6.0% (Baker, et al., 2009)

Contactless Inductance Charging	Contactless inductance loops allow vehicles with electric propulsion to charge while in motion, thus extending the range of the vehicle	Supports alternative propulsion methods	
Aerodynamic Fittings	Small aerodynamic adjustments to the cab or trailer reduce drag and fuel use	Reduces CO_2	2.0% - 4.0% (Atkins, 2010)
Expansion of Truck or Trailer Dimensions	Larger hauls contribute result in fewer heavier vehicles on the roadways, thus the expansion of truck or trailer dimensions systemically reduces fuel use	Reduces CO_2	10.0% - 30.0% (Morrison, et al., 2014)
Lightweighting	Use of novel lightweight materials reduces vehicle system weight and reduces overall fuel use	Reduces CO_2	1.5% - 3.0% (Atkins, et al., 2013)
Integrated Aerodynamic Design	Aerodynamic design of the total vehicle system (cab and trailer) reduces drag and fuel use	Reduces CO_2	10.0% - 12.0% (Baker, et al., 2009)
Low Rolling Resistance Tyres	Low rolling resistance tyres minimise frictional losses between tyre and roadway, and thus reduce fuel use	Reduces CO_2	4.0% - 8.0% (Baker, et al., 2009)
Optimised Mirror Design	Tailored cab and mirror design improves the driver's visibility of nearby road users	Safety-related	
Real-time Traffic Data	Provision of open-access real-time traffic data enables commercial software and application development for integration with in-vehicle information systems such as sophisticated satellite navigation systems	Supports advanced routing	
Natural Gas Infrastructure	Natural gas infrastructure supports long-haul journeys in vehicles using natural gas as alternative fuel	Supports alternative propulsion methods	
Telematic Data Collection	Telematic data collection supported by personal devices (e.g. smartphones) use accelerometers, GPS, and wireless connection to vehicle electronic control units to collect and analyse data related to driver behaviour	Supports eco-driving reviews	
Integrated Tachograph & Telematic Data Collection	Advanced telematic data collection and tachograph systems may be integrated for streamlined collection of data for legal requirements, driver monitoring, and real-time feedback	Supports eco-driving reviews	
Simulator Training	Driving simulators provide commercial vehicle driver training in a safe and controlled virtual environment	Supports eco-driving training	

Figure 1 shows projected future technology use as identified by industry experts in the short term, by 2020. These include technologies with a wide range of task demands, with the highest degree of automation being found for automated emergency braking systems. Items in Figures 1–3 denoted by an asterisk were identified for niche use only; in the short term this includes mild hybrid and stop/start systems.

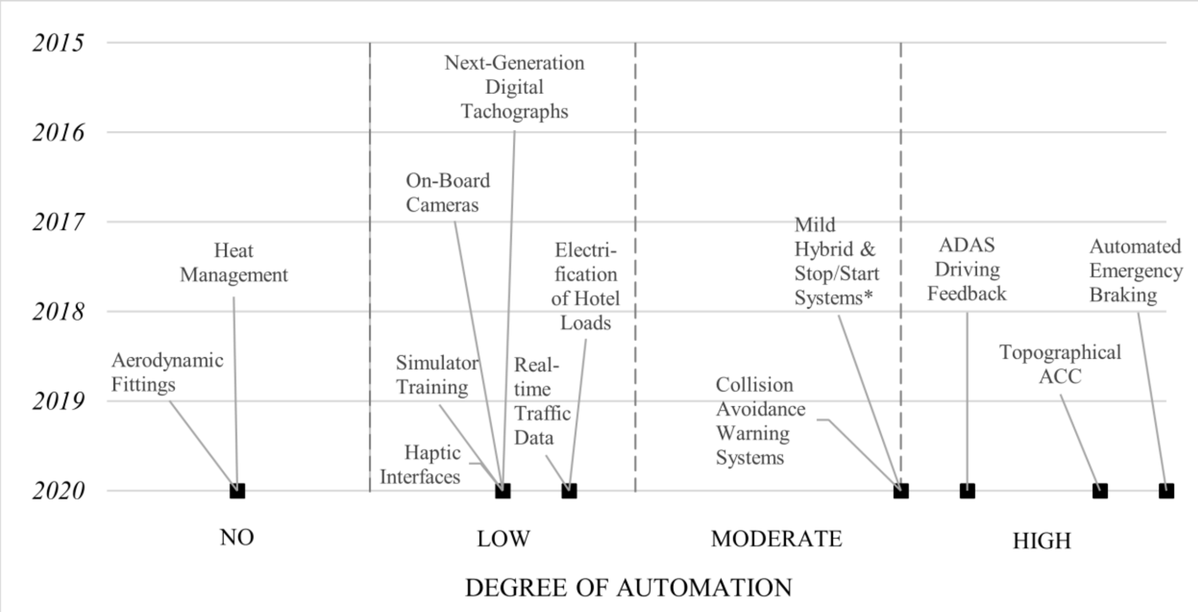

Figure 1: Commercial Vehicle Technologies in UK Identified for Short Term 2015-2020

In the medium term, technologies with a wide range of task demands are expected to be implemented. These include sophisticated infrastructure-to-vehicle communications, vehicle-to-vehicle communications, and other applications relying on surround sensor systems. At the highest degree of automation, active collision avoidance systems are designed to brake autonomously, as well as adjust the trajectory of the vehicle in the event of a collision with an oncoming vehicle. Electric hybrid vehicle use was identified for niche industries or applications by 2025.

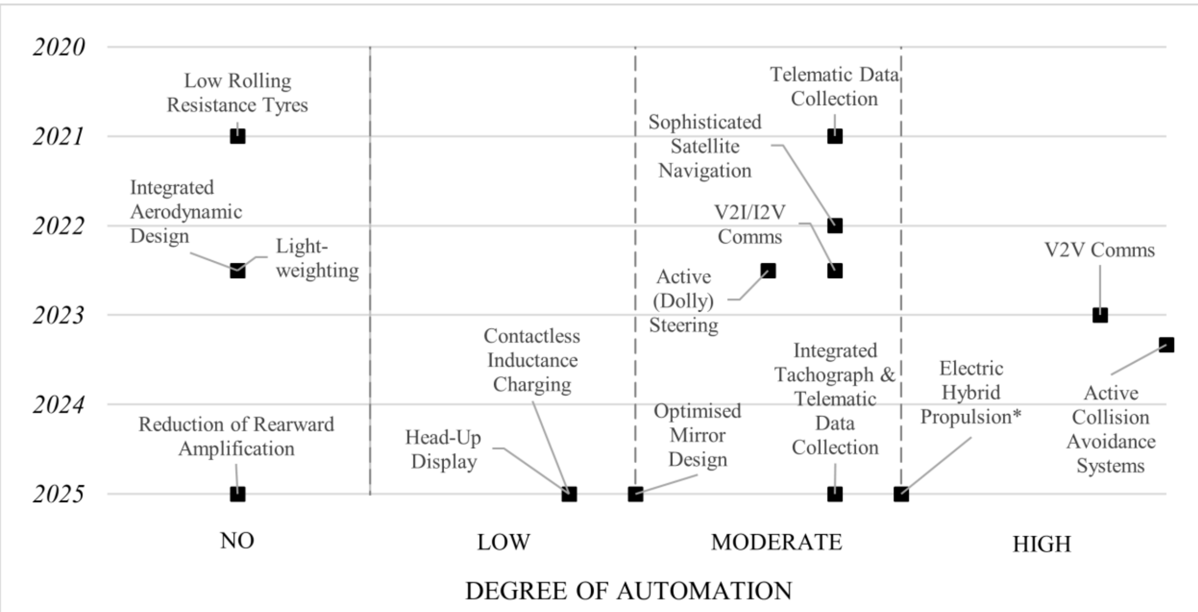

Figure 2: Commercial Vehicle Technologies in UK Identified for Medium Term 2020-2025

In the long term, many of the technologies identified fall in the range of moderate to high degrees of automation. The items identified out with this group were the expansion of truck or trailer dimensions by 2026, as well as the availability of natural gas infrastructure in 2037. Four of the ten technologies for implementation in the long term were identified for niche applications or industries only, including battery electric vehicles, dual fuel vehicles, dedicated gas vehicles, and hydrogen fuel cell vehicles. Technologies with the highest degree of automation included automated low-speed manoeuvring by 2027, and commercial vehicle platooning by 2033.

Many participants expressed caution regarding identification of novel technologies and applications beyond 2030, due to the 10-15 year life cycle of commercial vehicle development and uncertainty regarding future operating conditions. Although the majority of identified technologies were identified consistently by participants within a given time step, alternative propulsion methods (and supporting infrastructure) identified in Figures 1-3 carried the widest variability in time to implementation. This may be a reflection of each participant group's localised perspective of the system, or due to concerns surrounding a solid business case for such technologies, including the geographical availability of future infrastructure to reliably support operations-as-usual in terms of journey range (Ricardo AEA, 2012). While technology 'suppliers' may understand that interventions are technologically ready, the fleet operators who represent the majority of technology 'customers' may be more risk-averse; current research suggests that drivers report more support for the implementation of environmentally-friendly technologies, while operators' decision-making processes rely primarily on cost (Schweitzer, et al., 2008).

In order to link these individual technologies to an examination of system design, the degree of automation was considered in relation to the commercial driving task. Degree of automation characterises the task's allocation of function, by defining the contribution of technologies in terms of level of automation (low, moderate, or high), and across each of the four stages of information processing (information acquisition, information analysis, decision & action selection, and action implementation; (Onnasch, et al., 2013). This analysis was documented for each identified technology, and then aggregated for each time step (as depicted in Figures 1-3).

While high degrees of automation support routine operations, they also carry negative effects when the system malfunctions or fails; in layman's terms, this is referred to as the 'lumberjack effect', indicating that 'the higher they are, the harder they fall' in terms of recovery from system failure. The meta-analysis carried out by Onnasch et al. (2013) found that this effect is exacerbated in certain system designs, and a performance step change occurs when the design of automation shifts from allocation of information analysis, to decision and action selection. From the analysis of identified technologies, 'information analysis' was found to be the stage of information processing with the largest increase in allocation to technology between 2020 and 2050, followed closely by 'action selection'. Overall, this trend toward increasing emphasis of information analysis and action selection suggests that future technologies are at high risk for the 'lumberjack effect' whereby system performance under expected conditions is adequate, but in the event of a failure, disruptions are difficult to recover from. In the specific context of commercial driving and logistics operations, the degree of automation remains more or less constant over time, however the characteristics of such automation become generally more complex and more demanding of technological agents.

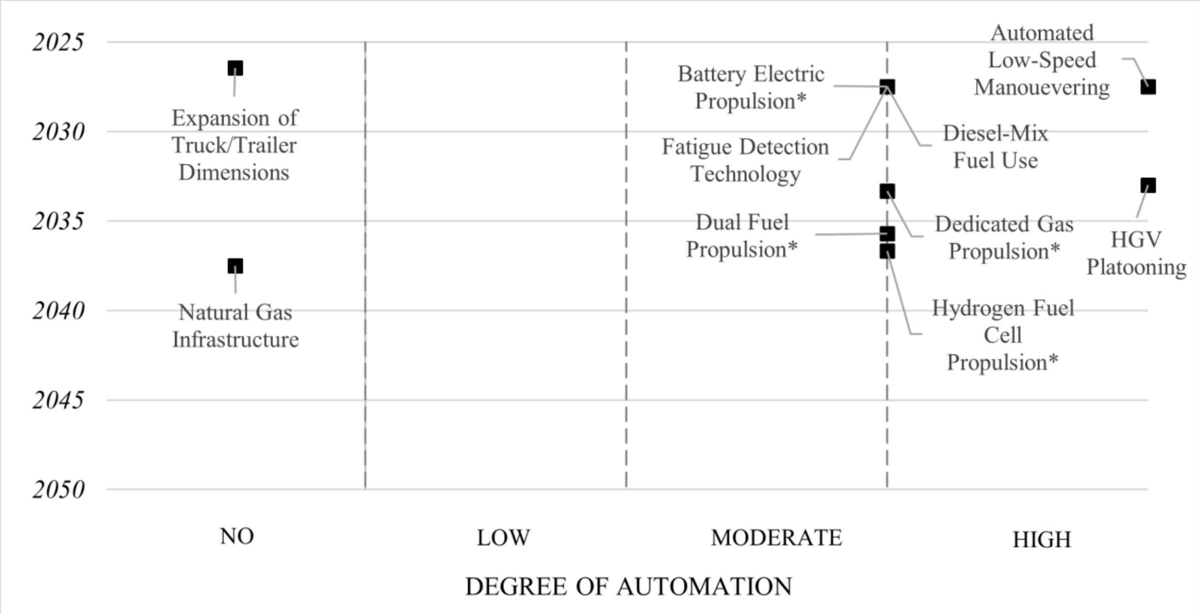

Figure 3: Commercial Vehicle Technologies in UK Identified for Long Term 2025-2050

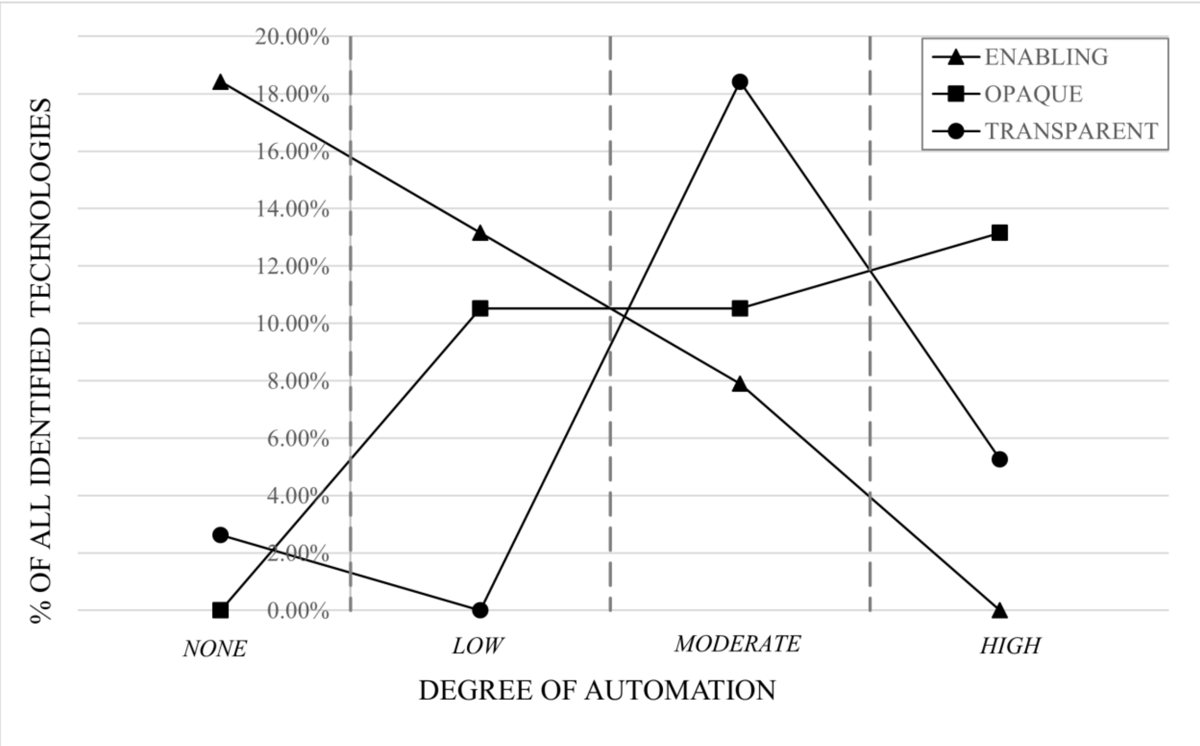

Figure 4: Proportion of Transparent, Opaque and Enabling Technologies Identified Mapped Against Degree of Automation Categories

Figure 4 also shows a broad relationship between technology classification and degree of automation. This shows that of the technologies identified by participants, enabling technologies occur most frequently at no or low degrees of automation. In contrast, opaque technologies were found most frequently at high degrees of automation. Interestingly, the proportion of transparent technologies varies with degree of automation; this suggests that the technologies designed to mediate and optimise interactions between vehicle and driver may not be apparent to the end user, but are projected to carry out a range of tasks with widely varying complexity.

More detailed characterisation of the system from this perspective may be used to highlight critical parts, and guide future system development. Specific end user characteristics may leverage human factors considerations such as the degree of automation; for example, the design of automation corresponding to various levels of stress (Sauer, et al., 2013).

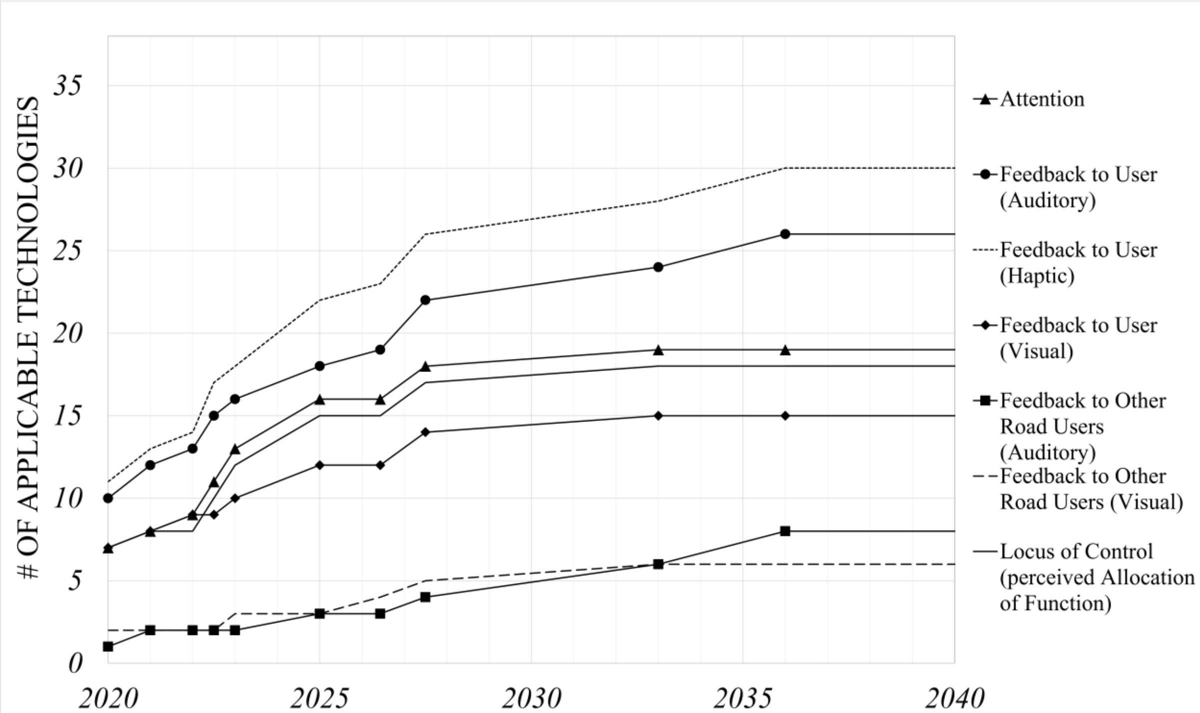

Figure 5: Associated Human Factors of Logistics Technologies in UK & their Aggregated Significance over Time

Figure 5 shows the potential human factors associated with each identified technology, and their aggregated significance over time. The highest relevance was found for haptic feedback, followed by auditory feedback, suggesting that total vehicle design will of significant importance to optimising the commercial driving task. The moderate significance of 'locus of control' at each time step of the trajectory along with the consistent increase in commercial vehicle automation over time suggests that an adequate approach for system evaluation will also include consideration of the allocation of function. Studies indicate that drivers may adjust their locus of control in a natural process of adaption to new technology over long-term use, carrying potential risks to safety or at the very least technological effectiveness in the case of system failure.

The risks associated with these factors – particularly the factors of locus of control and attention – may be exacerbated by a host of user and industry factors which hold more subtle influence over individual operational capabilities. This translates not only to ineffective carbon reduction approaches, but also to higher exposure to accident and injury to the driver or other road users (Day, et al., 2012). Further research might consider the extent of these human factors issues for each technology in the short-term and long-term of driver use (Saad, 2006). A fuller understanding of the commercial driver – and the role of knowledge, skills, abilities, and training required to perform the driving task – will be key to the evaluation of future commercial vehicle technology.

It should be noted that the human factors evaluation applied in this paper highlight generic human factors, and provide only a foundation for contextual analysis of each technology to determine more complex factors related to specific task settings. Haptic and auditory feedback maintained high significance throughout the targeted timeline, perhaps highlighting the prevalence of transparent technologies which provide feedback to the user despite little conscious interaction between human user and technology. Further investigation is required to conclusively determine the effects of implementation of identified technologies, however the high and increasing prevalence of feedback to the user may result in mode errors and problems with situation awareness.

Figure 6 presents a high level overview of general logistics trends offered by the expert participants. Short-term trends include the development of driver training legislation, and further customisation of vehicle technology to drive cycles and applications. In the medium term, we expect to see communications integration with intelligent transport systems, and the development of increasingly autonomous vehicles. In the longer term, specific legislation and regulation of autonomous vehicle applications are expected.

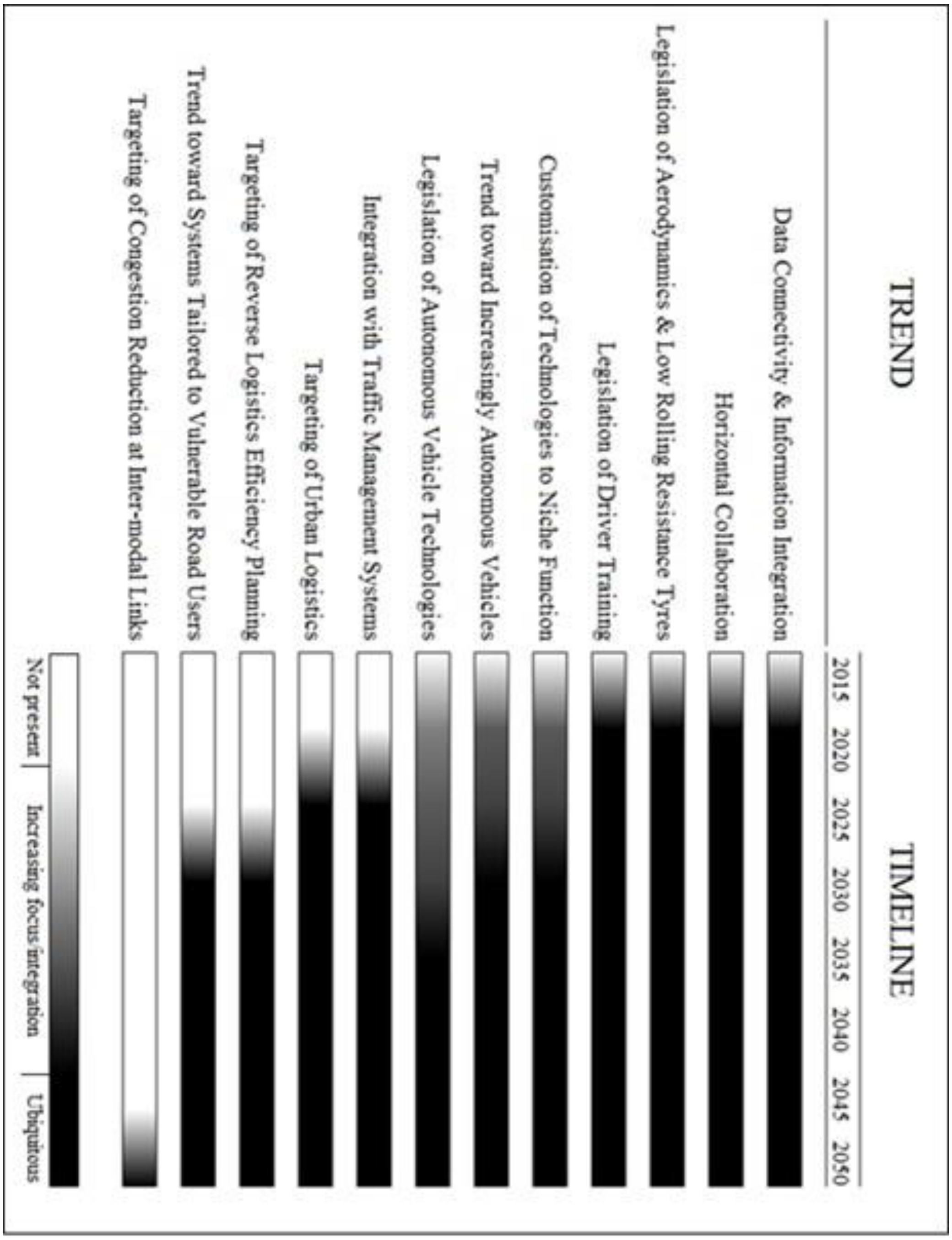

Figure 6: Commercial Road Freight Trends Volunteered by Expert Participants

Throughout the technology trajectory the changing nature of the driver role is acknowledged in driver training and legislation. Training is often the intervention of first choice when dealing with behavioural issues, but experience in applied ergonomics suggests a range of other potentially useful interventions. These include error-tolerant systems, adaptive automation, and designs which cleverly constrain behaviour so that the desired behaviour is the same as the easiest, most natural one for people to perform in real-life.

Any or all of the factors outlined in the end user profile may lead to higher exposure to accident and injury to the driver or other road users (Clarke, et al., 2009; Day, et al., 2012; Stuckey, et al., 2007), and as a result industrial responsibility for employee safety has gained importance in logistics. Although these factors may not all apply (as they have been studied in isolation for various driver types, and because of the specialised task and environment), these warrant further investigation and give reasonable cause for attention to human factors considerations specifically in a commercial driving context.

3.2. Trajectory of CO_2 reductions

The intended goal for many identified technologies is for carbon emission reduction, and based on industry estimates for engineering technologies, Figure 7 has been constructed to show progress in carbon reductions against future targets, and it can be seen that engineering technologies identified within the timeline fall short of achieving the required carbon reduction targets of 80% by 2050. This figure was constructed from an approximated range of carbon reduction estimates for each identified technology as cited in Table 2, and the most current national statistics available (Allen & Brown, 2008; Department of Energy & Climate Change, 2014; Department for Transport, 2009b; Department for Transport, 2009c; Department for Transport, 2010a; Department for Transport, 2010b; Department for Transport, 2012a; Department for Transport, 2012b). These statistics were used to estimate the distribution of miles travelled by each vehicle type as a proportion of the national logistics fleet, in order to coarsely assess the impact of projected technologies on a wider scale. These vehicle categories considered weight and drive cycle, and associated assumptions of the carbon reduction estimates in Figure 7 may be seen in Table 3 below.

Table 3: Vehicle Category Assumptions for CO_2 Reduction Projections (seen in Figure 7)

VEHICLE CATEGORY	WEIGHT RANGE	DISTANCE TRAVELLED*	PROPORTION OF DISTANCE TRAVELLED BY VEHICLE CATEGORY
	(tonnes)	*(km/year)*	%
Heavy duty / heavy goods	25 – 44	11,067,000,000	20.41%
Medium duty inter-city distribution	7.5 – 25	2,557,400,000	4.72%
Medium duty urban distribution	7.5 – 25	807,600,000	1.49%
Medium goods	3.5 – 7.5	3,149,000,000	5.81%
Light goods	0 – 3.5	36,630,000,000	67.57%

**approximated from Department for Transport (2010a); Department for Transport (2010b)*

The compatibility and 'stackability' (i.e. impossibility of co-implementation of certain technologies) (AEA, 2012, p. 45) of the identified technologies was then assessed for each vehicle category, and the appropriate carbon estimates for each category were used.

Based on consistent identification of alternative propulsion methods as technology only for niche applications, as well as uncertainty in the proportion of future uptake, such technologies have been excluded from Figure 7. Figure 7 relies heavily on the assumption that each engineering technology identified is adopted by 100% of applicable vehicle types, in order to illustrate that this shortfall is likely even under idealised conditions. As can be seen in the high occurrence of 'niche only' technologies in Figure 3 as well as the estimates in Figure 7, there may be diminishing returns gained by carbon reduction technologies over time from the implementation of engineering interventions in isolation. In fact, by 2030, many engineering technologies will be in widespread use, placing increasing emphasis on behavioural and systems solutions as time progresses.

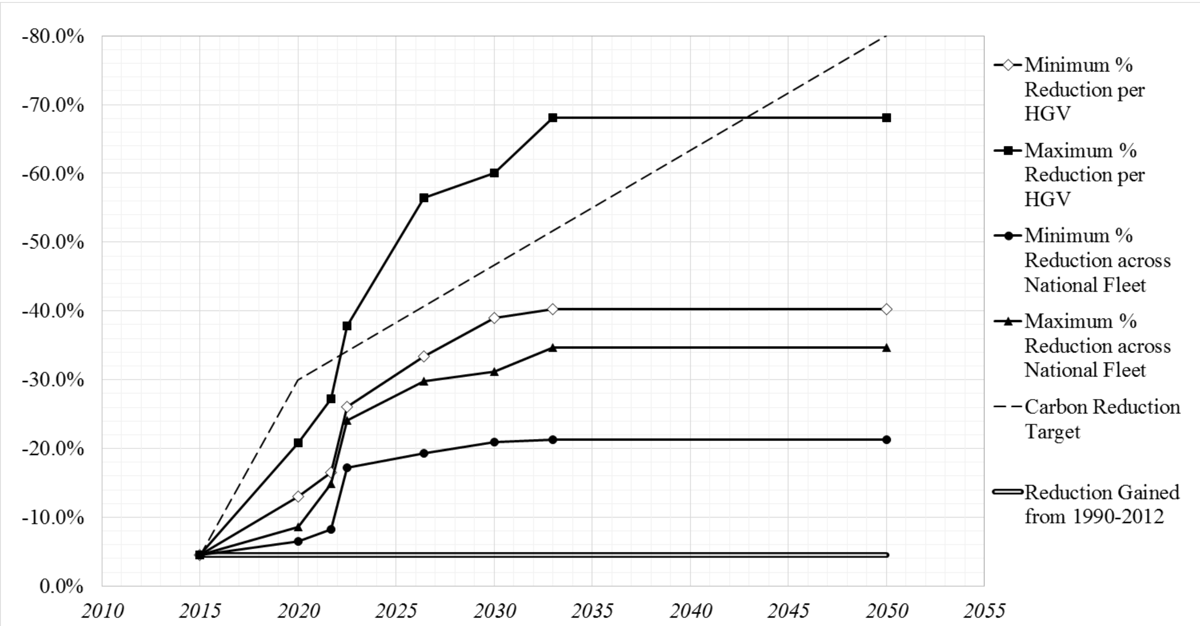

Figure 7: Estimated Carbon Reduction Gained by Identified Engineering Technologies (not including alternative propulsion methods due to uncertainty in proportion of uptake)

Even in the event of 100% uptake of identified engineering interventions, discounting increases in overall freight operations which are likely to accompany economic growth, and taking into account projected general engine efficiency improvements (AEA, 2012), Figure 7 supports that practical results will rely heavily on behavioural and systems considerations. Interview responses as shown in Figures 1-3 as well as Figure 6 confirm that while alternative propulsion methods may yield considerable environmental benefits per vehicle, uptake is likely to be limited to niche applications due to perceived risks associated with cost, ensuring infrastructure support, and uncertainty of the longevity and dependability of real-world commercial vehicle use (Ricardo AEA, 2012). The wide 27.85% gap between the maximum and minimum estimates for CO_2 reductions per HGV points to the complexities of technology trials in real-world logistics systems, and the need for contextual analysis to maximise practical impact. Interview responses also suggest short time frames of predictability and the sensitivity of the logistics system to time, which may delay the uptake of more radical technologies in risk-averse environments, further emphasising the need for deconstruction and analysis of one currently elusive influence: the human factor.

4. Is technology alone enough?

Is technology alone enough? The results of this study suggest that it is not. This work reveals the key to achieving mandated carbon emissions will increasingly rely on behavioural interventions and systems design. From the above results it is clear that future commercial vehicles will incorporate a great number and wide range of transparent, opaque, and enabling or systems technologies.

In place of a lengthy ordering of facts an alternative method has been chosen to convey the alternate realities that await the logistics sector, particularly the lorry driver, in the 21st century. This alternative method is to synthesise the findings into two test drives, in order to speculatively demonstrate the wide range of potential issues or benefits. Two optimistic and pessimistic theoretical commercial vehicle test drives are described below.

4.1. Scenario 1 – An Optimistic 2030 Test Drive

Before leaving for work, the driver checks their assigned tablet or phone and signs in to their profile on their organisation's app, which displays their truck and delivery assignment. When reaching the assigned truck, the driver notices some minor fender damage, and takes a picture with their tablet or phone which is sent with a time stamp to the vehicle depot garage, where the damage can be roughly assessed and parts can be manufactured from their 3D printer and replaced at the end of the driver's shift. The driver then switches to a tachograph app, and switches in to 'driving' mode through the touchscreen interface, which activates Bluetooth communication to connect with the CANbus and continuously collect vehicle dynamics data. This legally-required tachograph data is sent to a cloud storage point associated with the driver and their base office, along with the driver's 'shift profile' driving behaviour which is calculated in relation to a targeted delivery timeline, fuel efficiency, or eco-driving behaviour. The driver's fleet manager can track or review this information at any time, and the driver can opt to have this information sent to their profile or personal e-mail address in a weekly report, should they wish to examine their performance between meetings with fleet managers. To heighten the competition in order to sustain engagement with the program, weekly tables are posted (in an anonymised format) in the base office, where drivers can see the progress they have been making and their rank amongst the other company drivers.

The driver then starts up the vehicle, activating the advanced driver assistance system and the head-up display which provides the information for navigation, weather and road conditions, and rest stop areas. Route directions are displayed on the windscreen and are dynamically updated throughout the journey, based on real-time congestion data, roadworks information provided by infrastructure-to-vehicle communication, and the set dimensions and weight as calculated by the vehicle's CANbus. Moving through an outer urban area, the driver accelerates a bit too harshly, and the ADAS provides visual feedback on the windscreen, advising the driver to slow and 'smooth' this driving behaviour in order to optimise fuel usage. The driver continues on and attempts a left-hand turn, during which a cyclist in the driver's blind spot triggers the sophisticated active collision avoidance system which is continually feeding surrounding sensor data to the vehicle's computerised control unit. The sensors detect a possible (but not imminent) collision, and the ADAS collision warning uses a vibratory alert in the steering wheel. This haptic warning and the auditory warning coming from the dashboard draws the driver's attention immediately to the on-board safety camera visual, which has appeared in the head-up display. Paired with traditional mirrors which have been optimised based on interface guidance (built from information on blind spots and visual search behaviour) this enables the driver to manoeuvre cooperatively with the cyclist, avoiding an accident.

On arriving at the pick-up point, the lot is packed with vehicles. To minimise the waiting time for vehicles further down the queue, and the chances of getting into a tough spot or causing a safety incident in the lot, the driver pulls in and switches on the automated low-speed manoeuvring function which seamlessly and autonomously reverses the 40-tonne vehicle into the loading bay while using the sensor system to detect for nearing obstacles. The driver again uses the telematics tachograph application on their assigned personal device to switch to ‘other work’ mode, before switching off the vehicle and opening an app containing delivery information. After using the personal device to complete any administrative work and loading the vehicle with goods, the driver switches the tachograph app back on to ‘driving’ mode, and uses the dynamic force steering to manoeuvre easily around tight corners and spaces at the pick-up point.

Accelerating on approach to the highway, the driver works effortlessly with the vehicle, as despite the larger vehicle dimensions, greater payload, and intensive lightweighting, the truck-trailer combination has undergone an integrated aerodynamic design. Similarly, while the trailer unit is propelled partially by isolated electromobility and many other parts of the vehicle are controlled electronically, the computerised control unit continually optimises vehicle dynamics and stability. Entering the highway, the driver switches on the topographical adaptive cruise control (TACC), which communicates with GPS to project the gradient of upcoming terrain, and takes control of vehicle dynamics to optimise medium-term fuel usage. The CAS corrects the truck’s trajectory where necessary, ensuring that it remains between the lane boundaries. This same data is simultaneously used in determining the trajectory of oncoming vehicles so that in the event of a possible head-on collision, the truck can autonomously adjust its own steering and dynamics to create an aversive trajectory. Suddenly, a passenger vehicle traveling in the adjacent lane cuts in front of our vehicle, triggering the automated emergency braking which stops the truck just in time to avoid an incident. The driver regains control of the vehicle, and switches the TACC back on as traffic resumes normally.

Several other trucks on the highway join up with our driver, using vehicle-to-vehicle sensor communication to create an aerodynamically optimised vehicle platoon. The following drivers in the platoon take a supervisory role over their vehicles, and are able to finish some administrative ‘paperwork’ (completed via a tablet application) for their next destinations.

A few miles before reaching the off-ramp for the delivery point, the truck’s CANbus wirelessly sends notifications to the ADAS of surrounding road train vehicles that our driver will soon be exiting the platoon and the preceding truck in the queue will be required to take over. A roadside wireless infrastructure-to-vehicle communications point links the local area’s traffic management system in with the vehicle’s ADAS, and a warning appears on the head-up display regarding a point of congestion on the route which was projected by the satellite navigation system at the outset of the shift. The satellite navigation system suggests a route change to the next off-ramp, which under normal conditions would take a few minutes longer, but in this instance will save a substantial amount of time by avoiding the incident causing congestion ahead. The driver accepts this suggestion, and then switches off the TACC to make a lane change, and continues ahead to the next off-ramp in order to make it to the first delivery destination in a safe and timely manner.

After a long and tiring day behind the wheel, the driver is on the way back to the base of operations. It is dark and overcast, and the toll of the day causes the drowsy driver to close his eyes. The fatigue detection system, using an optical tracking camera, is immediately triggered by this behaviour and prepares to take temporary control to stop the vehicle. However, the simultaneous haptic vibration in the seat as well as an auditory alarm alerts the driver before this is necessary, and the ADAS projects the remaining miles on the journey onto the head-up display, and suggests a nearby rest stop location for a short break. After a temporary switch to ‘break’ mode in the tachograph app and having a strong cup of coffee, the driver returns smoothly to the base office and signs off, feeling satisfied with their driving style and performance in the face of today’s hard work and the next fleet manager meeting.

4.2. Scenario 2 – A Pessimistic 2030 Test Drive

Before leaving for work, the driver checks their assigned tablet or phone and signs in to their profile on their organisation's app, which displays their truck and delivery assignment. When reaching the assigned truck, the driver notices some minor fender damage, and takes a picture with their tablet or phone which is sent with a time stamp to the vehicle depot garage, where the damage can be roughly assessed and parts can be manufactured from their 3D printer and replaced at the end of the driver's shift. The driver then switches to a tachograph app, which requests an update before opening. After waiting several minutes for this to complete while in the depot, the driver switches in to 'driving' mode through the touchscreen interface, which activates short-range Bluetooth communication to connect with the CANbus and continuously collect vehicle dynamics data. This legally-required tachograph data is sent to a cloud storage point associated with the driver and their base office, along with the driver's 'shift profile' driving behaviour which is calculated in relation to a targeted delivery timeline, fuel efficiency, or eco-driving behaviour. The driver's fleet manager tracks company drivers in order to ensure they arrive at their destinations on time in the most fuel-efficient way possible, and if necessary in the case of delays or poor driving behaviour, can phone or contact the driver immediately. At meetings with fleet managers, most drivers don't mind the new technology however different drivers have a wide range of different driving styles, and different managers have varying levels of understanding regarding how the new technology functions. Some drivers receive weekly progress reports on their driving style and enjoy participating in the weekly tables – as all of the drivers know each other, it doesn't take long to determine which scores belong to which driver in the anonymised format. However, the majority see these eco-driving reviews as a 'check-the-box' exercise and view it as conflicting with the primary goal under real-world conditions – quick and incident-free delivery – thus are not as invested in the program when independently at work on the road. Some drivers have even learned to cheat the system by using unconventional manoeuvres such as avoiding the brake pedal and only applying the handbrake when deceleration is needed at low speeds. Not only do manoeuvres such as these cause considerable wear to the vehicle, but these also may increase overall emissions from abrupt deceleration and acceleration manoeuvres.

The driver starts up the vehicle, activating the advanced driver assistance system and the head-up display which provides the information for navigation, weather and road conditions, and rest stop areas. Although the ADAS contains valuable information, it's all a bit too much for the driver before even leaving the base depot, and the driver spends a few minutes minimising and adjusting the majority of the default visuals. Whilst personalising their own display, they are distracted from the immediate road environment, causing jerky, abrupt manoeuvres which increase emissions for the first several minutes of the drive. Using the sophisticated satellite navigation system, the driver begins moving through an outer urban area and on pulling forward through an intersection the driver perceives that a vehicle travelling in a perpendicular lane is not slowing down enough to come to a full stop. Our driver ignores the ADAS' visual feedback and accelerates harshly through the last of the intersection, in order to avoid an incident which might have been caused by the other driver's misperception of how quickly a heavy vehicle can accelerate from a full stop. The vehicle in front of the truck comes to a sudden stop, and the truck's sensors activate the automated emergency braking to bring the truck to an abrupt stop just before impact – and by sheer luck, our driver has already cleared the intersection at the rear, as the lights have again changed priority and traffic has resumed. Once the ADAS notifications have disappeared and traffic ahead has continued on, the driver moves forward and attempts a left-hand turn, during which a cyclist in the driver's blind spot triggers the sophisticated active collision avoidance system. The sensors detect a possible (but not imminent) collision, and the ADAS collision warning uses a vibratory alert in the steering wheel. This haptic warning and the auditory warning coming from the dashboard alert the driver, but of the many forms and locations of feedback, the driver is having a difficult time determining which type of hazard is being picked up on by the system. This is especially because the cyclist has now moved out of the scope of the on-board safety camera, and while the driver is checking the visual on the head-up display, the cyclist has changed lanes away from the scope of the sensors and mirrors. From the perspective of the driver, the ADAS collision warning could have been activated by any number of cyclists zipping between lanes and through traffic, or simply a technological glitch. Amidst the continuously changing stream of information the driver is processing about the surrounding traffic at this intersection, the collision warning is quickly and unconsciously shrugged off, and the driver continues toward the pick-up point.

On arriving at the pick-up point, the lot is packed with vehicles. To minimise the waiting time for vehicles further down the queue, and the chances of getting into a tough spot or causing a safety incident in the lot, the driver pulls in and switches on the automated low-speed manoeuvring function. All is going well until the surrounding activity in the lot repeatedly triggers the automated emergency braking, at which point the driver deactivates both the automated emergency braking and the low-speed manoeuvring function to perform the activity without interruption. The driver again uses the telematics tachograph application on their assigned personal device to switch to 'other work' mode, before switching off the vehicle and opening an app containing delivery information. However, the data connection is limited in this area and the wireless internet connection available at the pick-up point is strained from the number of users attempting to log on for their own delivery information. Our driver enters the pick-up point office, which is busy with drivers trying to sort out the details of their work in order to make it to their delivery point in time, and eventually receives the relevant information. After using the (slow, albeit functional) data connection to complete any administrative work on their personal device and loading the vehicle with goods, the driver switches the tachograph app back on to 'driving' mode and prepares to depart. The dynamic force steering is designed to navigate easily around tight corners and spaces but the driver, prepared to depart for the highway, is not expecting the sensitivity of the steering wheel, and thus harshly corrects manoeuvers in order to adjust their driving style and avoid collisions and scrapes in the lot.

Accelerating on approach to the highway, the driver feels disjointed from the vehicle, having to constantly adjust to unexpected handling characteristics produced by the combination of aerodynamic design and computer-optimised dynamics. Entering the highway, the driver switches on the topographical adaptive cruise control (TACC), which communicates with GPS to project the gradient of upcoming terrain, but at the start of the first incline the driver is unsettled by the lack of forward momentum and the feeling that they will roll back into traffic, causing them to switch the function off. The driver continues on, aware that the CAS corrects the truck's trajectory where necessary to ensure that it remains between the lane boundaries and providing an automated aversive trajectory in the case of an oncoming vehicle. The driver assumes that the CAS will take over in an emergency and deems the likelihood of an emergency low given the current traffic conditions, and so takes a few moments to readjust settings within the vehicle, change music playing from his personal device, and get comfortable. As the driver is refocusing his attention back to the traffic environment, a passenger vehicle traveling in the adjacent lane accelerates and cuts in front of our vehicle. While the driver begins to instinctively manoeuver by slowing down and slightly swerving, the expected auditory and visual collision warning are activated, but the automated emergency braking is not – in his rush to reach the delivery point on time, the driver has forgotten to turn the function back on after leaving the pick-up point. Although the driver's expectation is that the vehicle will take control and automatically stop, the driver manages to swerve into the next lane before regaining control of the near-incident.

After rejoining with the normal flow of traffic, several other trucks on the highway join up with our driver, using vehicle-to-vehicle sensor communication to create an aerodynamically optimised vehicle platoon. However, one truck in the middle of the platoon is alerted to one or two faulty sensors, which disables it from receiving the information necessary to integrate with the other trucks and forces the driver to exit the platoon. In order to retain some degree of fuel saving, this driver manoeuvers to the back of the platoon but remains disconnected. Although aware of the disconnection with vehicles in front, the driver's experience with platoons causes them to unconsciously maintain a slightly closer following distance than is safe without automated support. The lead driver in the platoon does not rely on semi-autonomous technology, but the following connected drivers take a supervisory role over their vehicles, allowing them to focus on other work tasks or have a quick bite to eat on the road. While several following connected drivers are simultaneously eating lunch, reading about safe rest stop location, and reviewing a driver performance profile from the previous week, the car traveling in front of the lead truck in the platoon decelerates harshly in reaction to an animal on the roadway. The lead vehicle's automated emergency braking is activated in time to avoid a rear-end collision, and while the following connected drivers are distracted from the driving task, the vehicle-to-vehicle communication allows them to remain unscathed. However, the driver of the final disconnected vehicle in the platoon has no field of vision to be alerted to the incident and a faulty sensor system which has disabled both collision warnings and the automated emergency braking. Due to the normalcy of a close following distance in a platoon setting, the final disconnected driver's close following distance and locus of control cause a delay in response, and a harsh rear-end collision results with the vehicle in front which is still connected to the platoon. The remainder of the platoon receives notifications of an incident on their head-up displays, however this provides few details. This allows the drivers who are still connected within the platoon to slow, and verbally communicate via the Bluetooth-enabled ADAS. There is considerable confusion about the events of the incident due to the fact that the final connected driver has now stopped and sensors are out of range resulting in a disconnection from the information circulating amongst the platoon. Once it has been assessed that only the last driver in the platoon has been affected, the unaffected section of the platoon is keen to move forward with their deliveries and to leave the involved drivers deal with the incident. Luckily, neither driver is injured, but both must call in the incident as each vehicle requires roadside assistance. Both have received automated incident report questionnaires which have been sent to their personal device after being activated by the vehicle dynamics data in the CANbus of their vehicle, which serve the dual purpose of incident reporting to the authorities and detailing insurance claims. While each driver is struggling to complete the section "Who do you believe is at fault for the incident and why?" assistance turns up on the scene and brings their attention to getting their vehicles evaluated and back on the road.

A few miles before reaching the off-ramp for the delivery point, the truck's CANbus wirelessly sends notifications to the ADAS of surrounding road train vehicles that our driver will soon be exiting the platoon and the preceding truck in the queue will be required to take over as lead vehicle. A roadside wireless infrastructure-to-vehicle communications point links the local area's traffic management system in with the vehicle's ADAS, and a warning appears on the head-up display regarding a point of congestion on the route which was projected by the satellite navigation system at the outset of the shift. The satellite navigation system suggests a route change to the next off-ramp, which under normal conditions would take a few minutes longer, but in the case of an incident will save a substantial amount of time by avoiding congestion. The driver accepts this suggestion, and waits for confirmation from the preceding vehicle that it is suitable to disconnect from the platoon. The driver eventually receives confirmation, but due to the distraction of following drivers this occurs only after passing the suggested off-ramp, and the satellite navigation system struggles to keep pace with the dynamic changes of the task. Preparing to double back, the driver continues ahead to the next off ramp and makes an exit while the satellite navigation system is processing new information from the roadside traffic management system points. Meanwhile, the head-up display is rapidly filling with rest stop suggestions and other local information. Eventually an optimal route is provided and displayed on the ADAS, but by the time it is provided the driver is forced to awkwardly manoeuver into another lane at the first junction in order to adhere to this route guidance. This is especially difficult given that the traffic management system is rerouting the majority of vehicles along this new route away from the originally reported incident, and as a result the local network is quickly becoming more congested. The driver has delivered to this location before, and being familiar with the area decides to switch off the ADAS and take roads they believe are likely to circumvent the major congestion areas in order to complete a safe and timely delivery.

After a long and tiring day behind the wheel, the driver is on the way back to the base of operations with all automated support enabled. It is dark and overcast, and the toll of the day causes the driver to rub his eyes. The fatigue detection system, using an optical tracking camera, is immediately triggered by this behaviour and releases a haptic and auditory alert, which startles the driver and causes them to swerve slightly while another vehicle is preparing to pass. Although the lane-keeping system is not activated due to the inability to detect faded markings at the roadside, the driver quickly adjusts and regains control, meanwhile becoming increasingly frustrated with the multiple "nagging" vehicle warnings and producing the temptation to deactivate any automated support. The ADAS projects the remaining miles on the journey onto the head-up display and suggests a nearby rest stop location for a short break, which is ignored by the driver in their determination to finish their day and return home, despite the driver allowing the notifications to remain on the display (potentially causing further distractions) due to fatigue. As night falls and the cab darkens, it begins raining heavily and the driver opts not to turn on in-cab lighting in order to avoid impairing his vision of the surrounding traffic. The driver's allows their eyes to close again just briefly, with the subconscious expectation that an alert will trigger the fatigue detection warning. However, the poor lighting conditions in the cab disrupt the system's ability to perform, and it is not activated; instead, the driver is awoken by an abrupt stop caused by the automated emergency braking system. As they regain awareness of the situation, the driver pulls to the edge of the road to assess the situation, and begins to dread the next review meeting with management due to the high rate of harsh driving behaviours which occurred throughout the shift.

The truck ends its day at the garage, however the maintenance check requested in the photo taken by the driver was bumped significantly in the queue due to a glitch in data connectivity at the start of the driver's shift. As a result, the truck will be out of service for the following shift and a driver has to be assigned to drive a temporary replacement truck from another depot some miles away.

5. Conclusion

Results indicate that future commercial vehicles and logistics distribution systems will be designed with increasingly complex automation, and that the nature of this increasing reliance on technology may also increase negative effects on system performance in instances of malfunction or failure. Examination of immediate human factors attributes as outlined within Section 2.4 may serve as a foundation for evaluation of current and future technologies, to be further elaborated on as necessary to ensure consideration of behavioural variability within this system, and set an industry precedent for 'human-in-the-loop' design. Results also indicate that a mix of technologies, practices and approaches will be necessary to achieve necessary emissions reduction targets, and that while a multitude of factors should be considered, a sound business case may be of central importance to the selection of interventions by logistics operators. This further supports future research into relatively low-cost, low-risk human factors research in the road freight sector.

In the pessimistic thought experiment, the ‘test drive’ showed the possibilities which support (or necessitate) behaviour which may be contradictory to eco-driving guidance and have practical implications for fuel efficiency. These considerations have a very real commercial and environmental impact to the road freight industry. However, it is also worth noting that for the purposes of illustrating as many of the identified technologies as possible, the experimental pessimistic test drive involves several instances of the driver quickly adjusting and regaining control of the vehicle in time to avoid an incident. Under real-world conditions, this is not always a guaranteed (or even likely) outcome. Any one of these instances may have resulted in a severe accident, cutting our thought experiment short with deeply serious consequences to our driver and his fellow road users. With an ageing workforce, the commercial driving sector may also experience greater difficulty with the acceptance of new technology, and systems require holistic design with consideration of this user demographic. This further stresses the importance of human factors design guidance not for the consideration of safety or environmental impact in isolation, but as a whole of interacting factors, and particularly as these pertain to the end user. In the first thought experiment, the optimistic test drive shows a glimpse of the potential of future technology and system design to achieve the triple bottom line. In order to ensure this potential is fulfilled and to maximise the impact of these results on wider system behaviour, future practice may incorporate a greater degree of user input throughout the design process. As a relatively new area of ergonomics research, exploration is also warranted for a wider range of systems issues within the commercial driving sector. This may include organisational factors, job satisfaction and potential links to ‘recruit and retain’ concerns currently expressed by operators. Future work includes the detailed examination of the commercial driving task; data and information communications structures necessary to execute critical tasks; the knowledge, skills, abilities, and training structure of commercial drivers, and; assessment of technologies in broader system design by human factors methods and future mapping techniques.

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