Implementing commercial autonomous road haulage in freight operations: An industry perspective

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Abstract

Interest from industry and policy makers on the use of autonomous goods vehicles (AGVs) for commercial use, has increased rapidly as the underlying technology has developed. This study looks at the potential impact of autonomous road haulage on logistics operations and barriers for commercial implementation in the UK. The research focuses on large goods vehicles, capable of automated driving, where the driver is not required for some or all of the journey, for logistics operations between suppliers, manufacturing plant, and retailer. The data is collected through semi-structured interviews and scoring questionnaires. All 76 participants had experience working in the logistics industry, from various parts of the operations process. The data was analysed using thematic analysis followed with the results subsequently ranked by participants to identify the importance and perceived impact. Results revealed a near-term barrier for adoption of autonomous technology, is the lack of standardisation, as technology is progressing in many different directions, with little consultation on what features are needed or how they will be implemented. The findings show the main impact of commercialisation of autonomous road haulage are overall maintenance cost reduction, due to less wear and tear, and operational cost reduction, especially for long-haul journeys, as vehicles can operate for longer hours. Moreover, despite barriers in the short term, such as public acceptance and transition costs, these will likely be outweighed by improvements in efficiency and utilisation. Based on findings from the study, we present six key considerations for the introduction of commercial autonomous road haulage, which can be used as a guide for policy makers, insurance companies, transport planning authorities, and vehicle manufacturers.

Keywords: Autonomous road haulage, transport policy, autonomous trucks, freight operations

1. Introduction

The development of autonomous vehicles (AVs) for transporting passengers is increasing rapidly, with many automotive manufacturers predicting their introduction into the global market, within the next 5 to 10 years (Freight Transport Association, 2019). The drive for greater vehicle automation is based on the potential for significantly reducing accidents, lowering emissions, and increasing transport accessibility (Fagnant and Kockelman, 2015). However, while the automotive industry has been working towards a holistic automation strategy for passenger vehicles (Talebian and Mishra, 2018), it can be predicted this will eventually be applied to freight transport, in the form of autonomous goods vehicles (AGVs) (Maurer et al., 2016). With predictions of having commercially viable autonomous trucks in the next decade (Costello and Karickhoff, 2019), many academic institutions and commercial organisations are working on how to bring the technology to market and benefit from first-mover advantage. This includes truck manufacturers, such as DAF Trucks, Daimler Trucks, Iveco, MAN Truck & Bus, PACCAR, Scania, and Volvo Group (Konrad and Wangler, 2018; Axelrod, 2019). Manufacturers of medium and heavy-duty commercial vehicles have already started to incorporate advanced driver-assistance systems (ADAS) and automated features to their vehicles, in an effort to gradually adopt autonomous technology, in preparation for the change in market demand by logistics

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companies. Modern trucks include features such as driver navigation, parking assistance, vehicle control, and traffic management (Gerla et al., 2014). The speed autonomous technology is developing is in part being driven by small and medium-sized logistics companies increasingly choosing to lease their trucks instead of purchasing outright. This has resulted in manufacturing companies having to implement the latest technology at a faster rate, in order to stay ahead of competitors (van Loon and Martens, 2015). Additionally, with vehicle leases, logistics companies are often not liable for maintenance costs. Furthermore, the difference between owner and operator of an autonomous truck raises questions around liability, universal legal systems, and how stakeholders will work together. This is partly addressed in ISO/TC 204 standards on intelligent transport systems (ITS) (ISO, 2000). However, as Alawadhi et al. (2020) states, there is still confusion around liability related to driverless vehicles.

The smart integrated nature of autonomous technology has the potential to reduce fuel costs, by using vehicle-to-vehicle communication, and spacing strategy to measure the distance between each truck. This can enable the platooning of vehicles, which are able to drive on motorways without the need for developing new road infrastructure (Larsen et al., 2019). This decreases the environmental impact and increases transport efficiency, leading to a reduction in cost (Gungor and Al-Qadi, 2020). The savings made from transporting goods using AVs will accelerate their introduction within supply chain operations. The concept of cost-saving and reducing lead times have invariably been implemented by logistics companies through efficient software and algorithms to optimise routes and delivery time for transporting goods and materials. The integration of intelligent routing systems in logistics is not new, in fact, similar intelligent software is used in various logistics operations (Woodman et al., 2019a).

Autonomous technology is currently being introduced to warehousing operations, as the movement of parts within a structured facility, is a less complicated task compared to similar activities in more complex unstructured environments, due to mapping and localisation technology issues (Conti et al., 2019). As this technology improves, it can be anticipated that it will be applied on a wider scale, to both inbound and outbound logistics operation, which has the potential to reduce fuel costs, and increase local transportation efficiency (Fritschy and Spinler, 2019). With the recent introduction of intelligent tracking and mapping systems, route management and avoiding transportation bottlenecks has become easier. This has shown to provide a smarter and agile distribution practice, reduction in load sizes and improve time-saving measures (Villarreal et al., 2017).

The impetus to bring AGVs into day-to-day supply chain operations is motivated by a need to improve strategic capabilities to stay competitive, through reducing lead time and cutting fuel costs. Additionally, driverless trucks would eliminate driver shortages and the disruption of driver turnover, which is becoming an area of increasing concern across Europe and the US (Ji-Hyland and Allen, 2020; Viscelli, 2018). Furthermore, AGVs will reduce the cost of having a driver and are predicted to reduce road accidents, promising operating cost savings, as there will be fewer issues with worker's compensation, payroll tax, and healthcare benefits (Freemark et al., 2019).

The development and acceptance of AGVs, which will allow for greater optimisation of the fleet, will have a sizeable impact on road haulage, leading suppliers, manufacturers, and other segments within the supply chain, to adapt their business models to take advantage of improvements in scheduling and lead time (Fritschy and Spinler, 2019). Already with the introduction of ubiquitous communication technology, many manual processes have been automated across the value chain; from order cycles, scheduling to delivery. There is still much that can be done in terms of making an autonomous supply chain agile, efficient, and productive (Sindi and Roe, 2017). The speed of change in technology to improve competitiveness and efficiency, suggests the need for higher-skilled jobs. The introduction of AGVs will require logistics providers to incorporate higher levels of automated platforms to remain competitive, as more players will enter the market to benefit from a first-mover's advantage.

The main focus of AV research to date relates to the technical challenges of implementing the technology, e.g. engineering, software development, and performance optimisation. However, there is increasing interest in how this technology will impact both the public and industry. From a thematic review of literature previously mentioned, there has not been significant research regarding the commercialisation of AGVs and issues associated with its introduction. A few papers address the practical implications of autonomous trucks in public spaces and the commercial introduction of the technology. However, these generally focus on reducing emissions and alleviating traffic congestion (Reis et al., 2020; Wang et al., 2019; Bhoopalam et al., 2018). Therefore, to address this research gap, this study focuses on the impact and barriers of commercial implementation of autonomous technology on road haulage operations. The study will examine the positive and negative effects from the perspective of logistics companies, and focus on the route between supplier, manufacturing plant, and retailer. This includes an analysis of current management of freight transport and logistics operations and how the introduction of AGVs may result in a possible change in operation management.

To narrow the scope, this study will focus on automated driving, where the driver is not required for some or all of the journey. This corresponds to level 4 automation (*no driver required for pre-set routes, e.g. motorways and A-roads*) and level 5 automation (*no driver required for any route*), of the SAE (Society for Automotive Engineering) J3016-2018 "levels of driving automation" (SAE, 2018). The SAE levels range from level 0 (fully manual control) to level 5 (fully autonomous control; no driver required). Levels 0 to 2 are considered "driver support features", whereas levels 3 to 5 are considered "automated driving features" (SAE, 2018). For level 3 automation, a human is required to be in the driver's seat to take control of the vehicle when the automated system is not able to safely maintain control. Therefore, this level will not be considered in this paper, as it requires the driver to maintain attention on the road and be ready to take control at any time (Bellet et al., 2019).

The vehicles considered are power-driven, having at least six wheels and used for the carriage of goods. An example use case is the movement of goods (long haul or short haul) from a manufacturer's warehouse to a distribution centre. Finally, the study will only consider vehicles used for the carriage of goods, with a maximum mass exceeding 3.5 tonnes (e.g. commercial truck), as per EU category N2 and N3 (UK Government, 2009). These are known as heavy goods vehicles (HGVs) and large goods vehicles (LGVs) outside of the EU. The main reason for this is to differentiate this study from a previous exploratory study into last-mile delivery AGVs, which considered only light commercial vehicles (EU category N1) (Sindi and Woodman, 2020).

The paper makes contributions to the literature, by presenting findings from a study of the impact and barriers of implementing commercial autonomous road haulage, in UK freight operations. This was achieved through a two-part study with experts from the logistics industry, which involved first conducting semi-structured interviews, followed by a theme-scoring questionnaire. The questions considered the issues presented by the introduction of AGVs and the incentives and disincentives that may present barriers for commercial adoption. Finally, this study presents six key considerations for the introduction of commercial autonomous road haulage. This is presented as a series of policy recommendations and design considerations that need to be addressed before commercial autonomous road haulage can form part of UK freight operation. These have been developed based on the study findings and would be relevant to transport planning authorities, policy makers, insurance companies, and developers of autonomous technology.

2. Literature review

With the rapid rise of automation and digitisation throughout the supply chain, truck manufacturers have started to view AVs, as a viable alternative to current manual vehicles. Truck manufacturing companies such as PACCAR and Leyland, who manufactures DAF premium light, medium and heavy-duty commercial vehicles, have been exploring truck platooning technology since early 2015 (Zhang et al., 2019). Although the autonomy level being implemented at DAF, is considered to be SAE level 3 (where the driver is still required in the cab) (SAE, 2018), it illustrates a change in direction, as manufacturers adjust to cater for a new wave in logistics demand. Leyland has recently launched the truck platooning EcoTwin project, together with NXP Semiconductors, the Netherlands Organisation for Applied Scientific Research (TNO) and the leading safety consultancy firm Ricardo (Reis et al., 2020). PACCAR and Nvidia are also collaborating in designing an autonomous navigation system for private trucks but are yet to implement it commercially (González et al., 2019). The Swedish start-up Einride has developed a semi-truck without the driver's cab, opting for autonomous or remote-controlled all-electric pods, built to help reduce Sweden's freight emissions by 40% by 2035 (Stern, 2019). Einride claims these T-pods will be able to haul 20-ton loads with a range of up to 124 miles per charge (Litman, 2019). Another application for autonomous haulage is shown by the company Daimler which has been working on autonomous and electric trucks and has tested self-driving semi platoons across Europe, their all-electric Urban eTruck concept is capable of travelling an estimated 124-mile range (Litman, 2019). In 2016, Volvo demonstrated how its autonomous trucks platoon to improve both safety and efficiency. The 35-ton trucks travelled down the highway autonomously; where the lead truck controls the accelerator and brakes of the two following trucks, meaning they all speed up and slow down together, thus removing the delays caused by driver reaction time. This method of platooning removes unnecessary braking and accelerating, and lowers wind resistance, which in turn increases fuel efficiency (Campbell, 2018). Current application of platooning is done on an SAE level 3 automation, where drivers still monitor their own steering. Volvo, which has partnered with FedEx, claims that if the computer-controlled trucks follow each other just one second apart, resulting in improving fuel economy by 10%, resulting in significant savings for haulage companies (Andersson and Ivehammar, 2019). Although AGVs have the potential to address driver shortages, freight companies are concerned with risks to driver safety, interaction with the technology and practical use of autonomous trucks on local roads, as Trösterer et al. (2017) discusses the technology needs to be proven safe, before its widespread adoption. Moreover, with the risk of potential reputation damage, due to the loss of employment opportunities for those in the trucking industry, freight companies would likely consider the impact of adopting the technology on their staff and if jobs can be transferred through upskilling.

2.1. *Current issues in road haulage*

There are several motivating factors for commercialising AGVs, such as meeting sustainability targets, reducing lead time, and keeping up with demand. One major motivation is the ongoing global shortage of truck drivers, which has increased over the last decade, with the rise of e-commerce and pressure for better scheduling to cater for same-day delivery and reduced turn-around time (Ji-Hyland and Allen, 2020; Viscelli, 2018; Nasri et al., 2018). Although the number of drivers employed in the logistics industry is increasing year-on-year, recruitment is not able to keep up with demand. The introduction of fully autonomous trucks may mitigate the driver shortage, although it requires government support and intervention before it can be commercially implemented (Clements and Kockelman, 2017). Therefore, it may be that commercial freight becomes an early adopter of autonomous technology, perhaps alongside, if not before, passenger AVs, due to the size of the fleets, better utilising of freight transport lead time and return on investment (Shanker, 2013). Moreover, due to long-haul journeys, autonomous technology provides more stress relief to the driver, which would not only increase driver safety, but allow better utilisation of time, for periods of relaxation and to complete other job related tasks. This would increase the attractiveness of the truck driver's workplace and the driver's commitment to the freight company (Hanowski et al., 2005). The EU has enforced laws on driver working hours, which does not account for the driver's state when starting their shift. With SAE level 4 vehicles, not only can the driver choose to give control when they feel under strain, but also the long-haul journey would only need to be interrupted for fuelling purposes. This would add flexibility to scheduling and lead time, which may result in faster turn-around time for freight. With SAE level 5 AVs, removing the constraint of the driver would change a fundamental limitation on the availability of trucks for transportation, adding further flexibility to scheduling and lead time.

Almost every industry in the UK relies on transporting goods, with the costs of logistics ultimately passed on to consumers. Therefore, it is likely that if the overall cost of adopting AVs reduces the cost of haulage, the cost of goods to the customer will decrease (Li, 2020). A recent study, which looked at cost-cutting measures in the logistics section, was conducted by AXA, a leading insurer of UK drivers, on behalf of the UK Government (AXA, 2015). Their research identified four key saving categories: labour, fuel, insurance, and vehicle utilisation. This is of great importance, as the freight transport and logistics (FTL) sector contributed £124B to the UK economy in 2018, with road freight alone generating £23.4B (Freight Transport Association, 2019).

Although there are no estimates of the number of truck drivers worldwide, the latest estimates show there are 3.5M professional truck drivers in the US (in 2019) (Costello and Karickhoff, 2019), and 300,100 HGV drivers (in 2019) in the UK (Department for Transport, 2020a). According to the American Transportation Research Institute (ATRI), 49.3% of trucking's operational costs is driver compensation, with the second-highest cost being fuel (17.7%) (Murray and Glidewell, 2019). The cost of drivers has been increasing rapidly over the last decade, with driver compensation being the biggest line-item cost for carriers since 2014. The reason behind this, according to the ATRI, is due to the shortage of truck drivers.

In the UK, 192,525 companies operate in the FLT sector, employing 2.7M people, with a turnover of £942.5B (Freight Transport Association, 2019). The majority of jobs are concentrated to lower-skilled occupations (49%), with 80% of companies employing 10 or fewer people, while only 1% employ 100 or more (Winters G., 2014). However, these larger employers account for 24% of those employed in the FLT sector (AXA, 2015). In the UK, 18% of FTL companies are in freight transport by road and 6% in courier activities. In the US, a report by the American Trucking Associations (ATA), found that in 2018, the trucking industry was short approximately 60,800 drivers, which was up nearly 20% from 2017's figure of 50,700 (Costello and Karickhoff, 2019). They further forecast that if current trends hold, the shortage could swell to over 160,000 by 2028 (see Fig. 1a). The ATA predict that in the next 10 years, the US trucking industry will need to hire nearly 1.1M new drivers. A breakdown of the reasons for this figure is given in Fig. 1b. As this graph shows, retirement, due to an ageing population, accounts for 54% of future need. The second-largest factor is industry growth at 25%, or more than 270,000 drivers.

Shortage of drivers is increasing year-on-year and has been exacerbated by the COVID-19 pandemic, with more people shopping online and the effort needed to keep grocery shops stocked (Reagan and Saphores, 2020). The

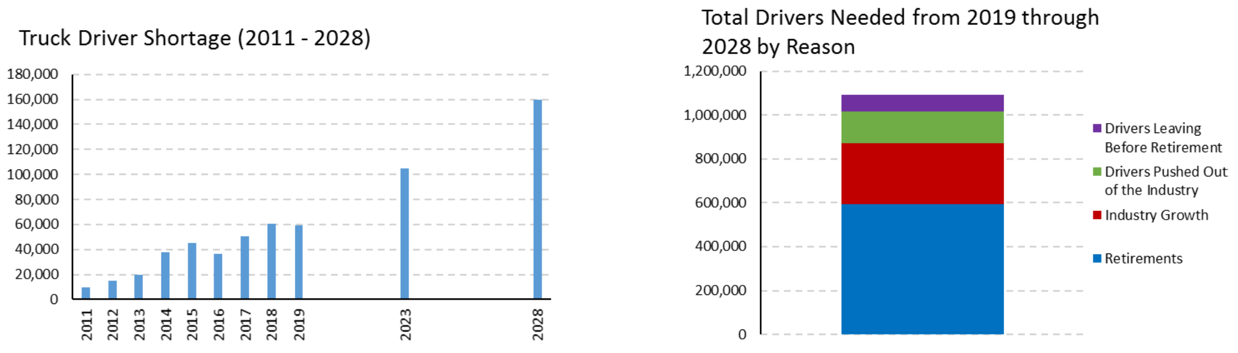

Figure 1: 2019 US truck driver shortage analysis by American Trucking Associations (ATA) (Costello and Karickhoff, 2019); (a) Truck driver shortage (2011-2028); (b) Total drivers needed from 2019 through 2028 by reason.

problem is further increased by the lack of qualified drivers and career desirability for younger generations. This calls for a skills-transition, which is a commonly cited cause of a skills gap, due to lack of experience from the staff being recruited. The lack of motivation from staff and the inability of the workforce to keep up with change are also factors that contribute to skills gaps (Freight Transport Association, 2019). In the UK it has been predicted that the effects of Brexit may result in a shortage of staff in the logistics sector, as the uncertainty over EU citizenship will result in a reduction of the availability of European labour, who accounted for 10% of commercial drivers in the UK (Kaye, 2019).

A study conducted by DHL showed there is an increase in demand for long-distance drivers in the freight industry for many developed countries. The reduction in interest to be a professional truck driver is attributed to the demanding hours, long periods of time away from home, and the dangerous nature of the job (DHL, 2014). DHL found these challenges can be overcome by autonomous technology applied in road haul transportation as trucks can travel the majority of the journey without the intervention of a driver, even perhaps complete the entire distance with no driver on board.

The rise in the number of vehicles on the road, causing increased congestion, raises concerns regarding capacity and efficiency of the sector (Department for Transport, 2018). In the UK, traffic is forecasted to grow by between 17% and 51% by 2050 from 2015 levels, with the proportion of traffic in congested conditions forecasted to increase by 8% to 16% (Department for Transport, 2018). Consumer pressure and market campaigns surround the need to mitigate the impact of freight transport on the environment. This has resulted in companies looking for ways to be more ecological, including training drivers to change driving behaviours and turn off their engines when possible (Ayyildiz et al., 2017). The aim is to help improve the technical skills of drivers and potentially save significant amounts of carbon (Piecyk M., 2013). With the introduction of AVs, the balance between transport, economy, and society can be achieved, as autonomous trucks can better optimise fuel efficiency, platoon to reduce carbon emissions, and utilise capacity, through encouraging logistics companies to share loads (Kockelman et al., 2017).

2.2. The potential impact of autonomous goods vehicles

The adoption of autonomous technologies into medium and heavy-duty commercial vehicles could potentially affect all areas of logistics operations cost, particularly that associated with technology and labour (Wadud et al., 2016). The potential for saving money on labour is likely to be greater for long-distance haulage, often referred to as *line-haul transportation*, as truck drivers can suffer from fatigue, which causes accidents, and loss of goods, as well as legal constraints on driver hours, accommodation expenses, and medical care. A study by Williams and George (2014), concluded that the main concerns for the implementation of AGVs are around legal liability issues, general safety, and reliability of autonomous driving technology. With the lack of reliability of autonomous systems, meaning that in the worst case, the truck would not be able to move (Richardson et al., 2017). This is due to the difficult balance the autonomous systems will be required to make, between ensuring the vehicle operates safely, while not imposing restrictions, which prevent it from operating at all.

For international freight travel, there will likely be more challenges compared to operating in a single country. This is due to several reasons, including difficulties with crossing international borders, varying infrastructure, different driving rules, and cultural norms, which affect driving style and adherence to rules (Mallozzi et al., 2019). Additionally, the cost of operating AGVs, compared to local labour cost, will limit economic viability in low-wage countries (Engholm et al., 2020).

Although we are several decades from truly driverless trucks being operated on public roads (Simpson and Mishra, 2020), ADAS technologies, such as lane-keeping assist and adaptive cruise control, have recently started to be included in new HGVs. This marks an important step, as although these features have been standard on most mid-range cars for a decade, the trucking industry has been late to adopt the technology over safety concerns (Richardson et al., 2017). These new assistive driving features, as described by Costello and Karickhoff (2019) have the potential to attract younger individuals to truck driving.

Public trust and acceptance of driverless technology need to be considered for AGVs, as although the general public will not be operating the vehicles, public opinion will influence policy makers' decisions on allowing the technology (Xu et al., 2018). For passenger AVs, several surveys have found that the majority of the public has a low level of trust of AV technology (Woodman et al., 2019b; Haboucha et al., 2017; Bansal et al., 2016). However, a recent study by Hudson et al. (2019) found that of the 1,000 people they surveyed, a significant proportion had a more positive attitude for autonomous trucks compared to autonomous passenger cars, with the study stating, "people are consistently more negative in their attitudes to cars than trucks". This was due to trucks generally not operating in residential areas, and not being seen as something that will prevent individuals from driving their car in the future. Another study by Pettigrew et al. (2019) highlighted the importance of providing the public with concrete information about AVs, to address fear levels and to resolve trust and control issues. A literature survey by Gkartzonikas and Gkritza (2019) examines nine hypotheses that predict a positive or negative influence on the intention to use AVs. These include the level of awareness and self-efficacy, as positive influences, and safety and environmental concerns as negative influences.

The cost of fuel is one of the highest operating expenses in the haulage industry, preceded only by salary costs. Engineering studies found potential fuel savings from multiple autonomous trucks platooning together (Dougherty et al., 2017). This can be seen as several trials were done using AGVs, where 12 AGVs platooned together in a European cross-border journey, where the leading truck achieved 5% on fuel saving and the following trucks achieved between 10-15% (Nasri et al., 2018). AGVs cannot travel faster than the given speed limit, and with unpredictable conditions such as weather and congestion, customers might face unpredictable delays, which can add to the total logistics cost. Although truck drivers can exceed speed limits, issues such as weather and congestion also affect normal truck operation, where the AGV has an advantage to make up the lost time due to longer working hours. However, when the traffic speed is high, the fuel consumption of AGVs is also high, if the AGV is to travel at the given speed limit in all situations, it will not choose routes with high speed limits as it will increase fuel cost (Katrakazas et al., 2015). According to Nasri et al. (2018), if speed is considered a decision variable, the vehicle will have the ability to travel at a speed slower than the traffic speed, allowing it to make fuel savings without compromising root selection. This type of optimisation also has implications for the design of smart cities, as if drivers are no longer a consideration, the landscape for service stations could change, as the stations will not need to be designed for people (Huang and Kockelman, 2020). Therefore, only requiring services for the autonomous truck (fuel, power, quality check, low-level maintenance, and monitoring). This could result in smarter distribution practices, reduction in load sizes, in addition to other cost and time-saving measures (Lom et al., 2016).

Safety is a common theme when discussing AVs, with the potential of reducing accidents, as a result of increased reaction times and strict adherence to driving laws. In 2019, the UK Government reported 4,064 casualties involving HGVs in Great Britain, with 19 road users and 52 pedestrians killed (Department for Transport, 2020b). For AGVs, there would also need to be consideration given to other road users particularly those more vulnerable (e.g. cyclists) and safety implications of goods on the vehicle. A study by Clements and Kockelman (2017) looked at the idea of using dedicated lanes to separate AGVs. Participants of the study viewed this concept positively, however, when combined with the idea of platooning trucks, responses were mixed. This was due to the potential risk of blocking exits or trapping faster moving vehicles.

Bansal et al. (2016) carried out a survey capturing people's attitude towards autonomous vehicles, they found the most common concerns related to system failure, problems interacting with other vehicles, and affordability. A similar study by Kyriakidis et al. (2015) used an online survey of 5,000 people from 109 countries. The concerns from the responses focused on software hacking/misuse, legal issues, safety, the ability of vehicles to deal with unexpected situations, legal liability, and privacy issues. The benefits are related to emissions reduction and fuel consumption. Interestingly in a study by Haboucha et al. (2017), the authors found some nationalities are significantly more positive about AVs than others. Although attitudes to AVs may be associated with driving standards in the individual's country, due to the number of fatalities associated with driving, generally, much of the literature tends to find a relationship between attitudes to technology and socio-economic characteristics, with younger people, men, and the well-educated, tending to be more in favour (Yerdon et al., 2017).

3. Research method

This study aims to identify key issues logistics companies perceive in the introduction of autonomous road haulage. These issues were collated and analysed to produce several policy and design recommendations. This was achieved through a two-part study, which involved first conducting semi-structured interviews, followed by a theme-scoring questionnaire. The research was conducted from an objectivist perspective with an emphasis on identifying themes from the data.

The design of the semi-structured interview questions, which are provided in Appendix A, follows a cognitive process, as it uses existing knowledge from the researchers, who have experience of AV research and development, and have worked in both the logistics and automotive industry, to generate new knowledge through the execution of the study (Ritchie et al., 2013). The interview strategy we used, which was based on two studies by Fraedrich et al. (2019) and Morton et al. (2019), encourages participants to use their knowledge of logistics operations and apply that to a scenario where AGVs are used instead. To aid this process, participants were provided with a brief description of the different level of autonomy and encouraged to ask any questions about the use and limitations of the technology. Each interview lasted approximately 30 minutes and explored each question in-depth, covering several related issues in the process, e.g. environmental impact, cost, etc. Interviews were conducted via video call using Skype and Zoom and were recorded by permission of the participants. All participants were eager to discuss the subject of AVs in the logistics industry and were able to provide a response to each question asked.

The usefulness of interviews has long been recognised, as this qualitative method tends to provide detailed descriptions of events (Seidman, 2006). Interviews are an appropriate method for this study, due to the exploratory nature of the research. As Kvale and Brinkmann (2009) stated, interviews help "shed light" on events that are often not directly "observable". According to Alsaawi (2014), a "good" interview has two key features; it flows naturally, and it is rich in detail. To achieve this, a checklist was created to ensure the semi-structured interview covers all relevant areas, as advised by Berg (2007). Gomm (2008) add that interviewees responses will be shaped, to some degree, by the questions they are asked. Therefore, to ensure reliability, the study gave participants the opportunity to add any further information they thought was not covered by the questions. However, it must be acknowledged that participants will be discussing some concepts and situations, which they may not be familiar with. Therefore, the role of the interviewer is to help participants relate past experiences and knowledge to new concepts while avoiding imparting their own views (Leavy, 2014).

3.1. *Thematic Analysis*

To interpret the semi-structured interviews, an inductive bottom-up approach is taken using thematic analysis (TA), which is a method of cluster analysis for qualitative data (Braun and Clarke, 2006). The process focuses on identifying patterns within the data in order to extract meaning (Lawless and Chen, 2019). In our study, the data is in the form of semi-structured interview transcripts. Therefore, the TA process requires a careful analysis of each word and sentence to identify how it relates to the questions asked. This involves a number of steps. The first is data familiarisation, which requires first reading the transcript, to understand the overall meaning of what the participant is saying and the strength of the statements. The second step is codifying all parts of the transcript that is relevant to the research question. This involves generating succinct codes that identify important features of the data. These codes are then collated into categories, in order to find broader patterns of meaning within the data. Finally, themes are generated, which describe the data in a narrative way. Often main themes can be used to explore the research question further. To give context to the TA, participants responses are quoted, as per Bechhofer and Paterson (2000) recommendation, as quotes provide invaluable interpretations.

TA is a proven technique for identifying and grouping themes from interview data. In order to understand the themes and ideas that come from the analysis, it is possible and often desirable to record the frequency of each code and category identified. Furthermore, it is possible to assign a weighting to certain responses, based on the relative strength of the words used (i.e. if the words like "very", "hate", "great", etc.). However, although this can reveal more certainty about a response, it can be difficult to apply accurately, due to the subjective use of adverbs and misinterpretation by the researcher. Therefore, in this study, we combined TA with a theme-scoring method, which takes the themes and other key identified issues and presents them in a questionnaire (Correll and Heer, 2017). This questionnaire was then presented to the original participants in order to gain their perspective on the relative importance of key issues.

3.2. Participant sampling

The participants, all of which have experience from working in the UK road freight sector of the logistics industry, were obtained through a variety of recruitment strategies, such as direct contact with industry, government-funded projects and links with universities, as well as professional contacts, and networking. All participants had a minimum of 8 years (M=11.67, SD=4.91) experience in the logistics industry, from various parts of the operations process. The main area of responsibility for each is broken down as: management/leadership (25.0%); operations (22.4%); warehouse (19.7%); depot (11.8%); sustainability and corporate responsibility (10.5%); and goods vehicle driver (10.5%). Additionally, several participants have also previously worked as a professional goods driver, giving a total of 19.7% having driving experience. The areas of responsibility that participants were recruited from, was determined before recruitment started. These areas were chosen to give a broad perspective of the road freight sector of the logistics industry.

To ensure the reliability of the data, obtaining a suitable sample size is necessary. However, the final sample size can be continuously evaluated during the research process. A commonly used principle for determining sample size in a qualitative study, is when n should is sufficiently large and varied to elucidate the research aim (Patton, 2015). The larger the information power a sample holds, the lower n is needed and vice versa (Carlsen and Glenton, 2011). With exploratory analysis, the ambition is not to cover the whole range of the phenomena, but to present selected themes relevant for the study aim. The sample size of participants used for the semi-structured interviews was determined by data collection reaching response saturation. The data collection was completed, once responses reached the point at which no new information was being provided by participants. The semi-structured interviews were conducted using a sample of 76 participants from the logistics industry, which was the point the study reached data saturation. For the theme-scoring questionnaire part of the study, two participants did not take part, as we were unable to contact them. However, as this only represented 2.6% of the sample, it was deemed to have not inordinately affected the results.

3.3. Limitations

It is important to acknowledge the difficulty inherent in asking questions about technology, which does not yet exist. However, in this study, we have made every effort to contextualise all questions to make them relevant to current logistics industry operations and practices. For example, when discussing the driverless aspect of AGVs, we focused on the issues with not having a driver present in the truck and not about the technology. Additionally, participants were asked to consider current autonomous features that are commercially used, (e.g. autonomous parking, lane-keeping assist, live GPS, and satellite navigation), and how these autonomous features impact their operation or provide barriers to their implementation on an advanced scale in freight transport. These mitigation strategies proved successful, as participants were able to relate their current logistics operation, with the concept of introducing autonomous trucks into their fleet.

As this study was concerned with the commercial implementation of AGVs in freight operations, participants were selected based on industrial experience in the logistics industry. Although this allows the study to understand an industry perspective, it does mean that the results may not reflect the views of people in other industries or the general public. However, to mitigate the impact of this, the study focuses on aspects of AGVs, which are most relevant to road haulage.

4. Results

The results are divided into two sections, the first presents the semi-structured interview thematic analysis, and the second presents a scoring of the themes. This is followed by a discussion of the findings.

4.1. Semi-structured interviews

Semi-structured interviews were carried out with 76 participants, with professional experience in the logistics industry. The main questions asked are provided in Appendix A. However, several other additional lines of questioning were explored with all candidates during the course of the interview, including the cost of introducing autonomous technology, public perception, lead time, driver shortages, and environmental impact of autonomous vehicles. Two questions were asked to only participants in a management/leadership or operations role, as these were related to the cost of drivers.

Thematic analysis was applied to the interview transcripts using the computer software package NVivo 12, which took two researchers a total of 200 hours. This generated a total of 2,780 first cycle codes. These were further refined, as part of a second coding cycle, into 239 codes, each of which represents a single idea. These codes were then grouped into 69 categories, each labelled with a phrase that described a group of codes and represented a collection of coherent ideas. Finally, these categories were further analysed against the original transcripts, which produced nine distinct themes. These themes and categories, with corresponding coding frequencies, are presented in Table 1.

The theme "impact of removing driver" had the most associated codes (f=594). This is also closely related to the theme "impact of reliance on driverless technology" (f=206). However, it was deemed distinct, as the former was considered more of a strategic issue (relating to loading/unloading, alertness of the driver, and reporting issues associated with the journey, vehicle, and collection/delivery) and the latter an operational issue (relating to the reliability of the system in different environments/weather conditions, compatibility over time, and reliance on machines over humans). The theme "impact on public perception" has the least number of codes associated (f=111), although there were enough responses in this area to justify having a distinct theme. The "safety" category had the most associated codes (f=135), followed by "accidents" (f=112). These categories are interrelated, and both cover the safety of transporting goods by an autonomous vehicle. However, many of the comments from participants around safety, acknowledged that one of the benefits of AGVs is perceived safety. A point that was echoed by several participants (14.5%), was that if there were no human presence in the vehicle, it would eliminate the current risk to drivers during transit. However, it was also made clear that autonomous technology should not be used if it resulted in more accidents or an increased risk to the public.

Participants were asked if they support the introduction of AGVs. The results show that 46.1% do not support the introduction, citing reasons around safety, loss of jobs, and cost; 36.8% said they did, citing reason around the reduction in emissions, better scheduling, and accident reduction; and 17.1% were undecided. All participants acknowledged that automation in the road freight sector was increasing, with examples being given of new vehicle ADAS features, loading systems, and advancements in transport infrastructure.

Analysis of the participants' responses identified key areas of thinking around the area of commercial AGVs. However, from these results, it is difficult to understand the relative importance of the themes and to what degree they are perceived as having a negative or positive impact on the logistics operations. To understand this relationship, we conducted a second round of testing with the same sample, which is presented in the section that follows.

4.2. Theme-scoring

Thematic analysis of the interview transcripts revealed nine themes. For each of these themes, we recorded the frequency of codes. Although this gives an indication of the importance of each theme, the strength and conviction of statements are generally lost during coding. Therefore, after TA was completed, participants were asked to evaluate the identified themes, by means of a questionnaire, scoring them on both order of importance and positive/negative impact to the road haulage logistics industry. Of the original 76 participants, two were not available for the second testing round.

To understand the importance of each theme, participants were asked to choose the three most important themes, in terms of impact, as a result of the introduction of commercial AGVs, and rank them in order of importance (Fig. 2). Overall "impact on employment" received the highest number of selections (n=46) and "impact on public perception"

Table 1: Themes and categories captured as part of thematic analysis. Total code frequencies are given for each theme and each underlying category.

Impact of removing driver (f=594)	**Impact on direct and indirect fleet costs (f=495)**	**Impact on safety (f=446)**
Loading and unloading (83) Breakdowns (82) Issue reporting (74) Paperwork (68) Keeping stock on trailers (61) Dangerous loads (59) Driver's hours rules (47) Reliance on drivers (35) Sleeper cab (33) Securing load (27) Roadside vehicle checks (25)	AGV cost (85) Infrastructure cost (79) Labour costs and ROI (77) Transportation cost (74) Maintenance (67) Insurance costs (43) Tax relief (38) Government incentives/ disincentives (32)	Safety (137) Accidents (112) Liability (62) Careless driving (other road users) (52) Human error (43) Theft (40)
Impact on lead time (f=317)	**Impact on employment (f=297)**	**Impact of reliance on driverless technology (f=206)**
Lead time (66) Vehicle speed (62) Traffic (37) Fuelling/charging (35) Efficiency (31) Scheduling (22) Time sensitive journeys (19) Route optimisation (16) Backloads (14) Blocked roads/detours (9) Cycle time (6)	Job losses (78) Retaining drivers (65) Training (54) Job security (47) Recruiting drivers (42) Trade unions (11)	Operating domain (42) Driverless vs humanless (39) Driverless vehicles (36) Transition to new technology (21) AGV capability (19) Proven technology (14) Height restrictions (12) Weather conditions (9) Road surface (8) Right-of way (6)
Impact on data sharing and data security (f=171)	**Impact on reliance of third-party companies (f=144)**	**Impact on public perception (f=111)**
Mixed fleets (48) Data protection/security and GDPR (36) Warehousing (33) Cybersecurity (29) Platooning (14) Connectivity (11)	Standardisation (33) AGV manufacturers (32) leasing vehicles (27) Maintenance (19) Alliances with others logistics companies (14) Outsourcing (12) Ownership (7)	Unwanted media attention (25) Publicity (23) Accidents (21) Crisis control (18) Eco compliant (13) Sustainability (11)

Theme	*n*	Mean	% selecting item	Ranked first	Ranked second	Ranked third
Impact on employment	46	2.02	20.72%	14	17	15
Impact of reliance on driverless technology	40	1.70	18.02%	19	14	7
Impact on lead time	37	2.08	16.67%	12	10	15
Impact on direct and indirect fleet costs	33	1.85	14.86%	13	12	8
Impact on safety	32	2.13	14.41%	8	12	12
Impact of removing driver	23	2.17	10.36%	7	5	11
Impact on data sharing and data security	7	2.57	3.15%	0	3	4
Impact on reliance of third-party companies	3	2.67	1.35%	0	1	2
Impact on public perception	1	1.00	0.45%	1	0	0

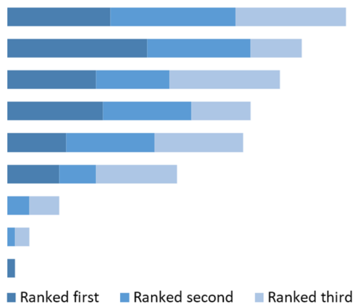

Figure 2: Perceived importance of each theme to road haulage logistics in the UK. Each participant (n=74) ranked their top three themes against the given criteria.

Theme	*SD*	*Mdn*	Mode
Impact on employment	1.86	2	1
Impact of reliance on driverless technology	1.52	3.5	4
Impact on lead time	1.83	4.5	6
Impact on direct and indirect fleet costs	1.83	3	3
Impact on safety	2.33	2.5	1
Impact of removing driver	1.14	1	1
Impact on data sharing and data security	1.05	2	2
Impact on reliance of third-party companies	1.08	4	4
Impact on public perception	1.27	4	4

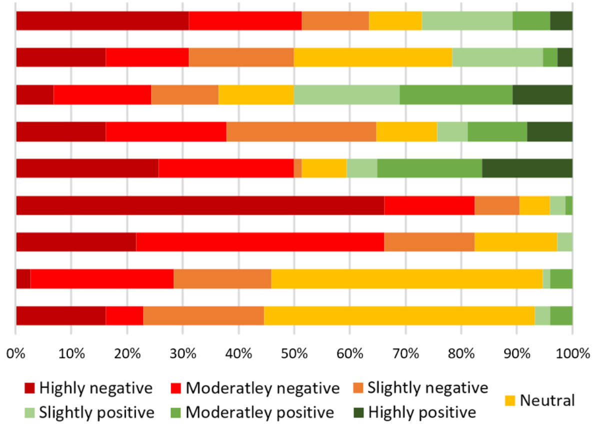

Figure 3: Perceived positive/negative impact of each theme to road haulage logistics in the UK. Participants (n=74) choose a score for each theme based on a 7-level Likert scale (from 1 = highly negative to 7 = highly positive).

received the least (n=1). The theme that received the most first rankings was "impact of reliance on driverless technology" (n=19). This theme also received a low mean ranking score (average of the first, second, and third-ranked scores) (M=1.70). This is significant, as it is a good estimate of the average view of all participants. It is important to note that the two themes which received the most rankings, "impact on employment" (n=46) and "impact of reliance on driverless technology" (n=40) had, respectively, the fifth and sixth-lowest number of associated codes identified during thematic analysis (Table 1).

To understand the relative impact of each theme to road haulage logistics in the UK, participants were asked to assign a Likert scale value, from 1 (highly negative) to 7 (highly positive). From the results, which are presented in Fig. 3, it can be seen that lead time received the highest median score (Mdn=4.5, SD=1.83), with 50% of the scores showing a positive impact. Removing the driver was perceived as having the highest negative impact (Mdn=1, SD=1.14), with over 60% of the scores showing a highly negative impact. Finally, both reliance of third-party companies and public perception, received ≈50% neutral scores, which reflects the sentiment of participant interview responses, as the majority (61.8%) were unsure what the effect would be.

The section that follows discusses the results of the study in the context of the literature.

5. Discussion

Thematic analysis and subsequent theme-scoring, in addition to the review of literature, provided insight to what is considered an impact and barriers for the commercialisation and introduction of autonomous road haulage into logistics operation. This section looks at each theme individually and discusses the potential impact and if it represents a barrier or a benefit. These findings are subsequently presented as six key considerations for the introduction of commercial autonomous road haulage from the perspective of the logistics industry. This includes policy recommendations and design considerations, to mitigate some of the identified issues and provide incentives for logistics companies to adopt the technology. Finally, it should be remembered that the results and subsequent discussion are based on the perspective of those working in the road freight sector of the logistics industry and may not reflect the views of people in other industries or the general public.

5.1. Analysis of themes

5.1.1. Impact of reliance on driverless technology

The theme of reliance on driverless technology is similar to that of removing the driver. However, reliance in this context is from a strategic perspective. Therefore, it relates to the impact of the logistics company relying on both autonomous trucks as a mode of goods transport.

Discussion of driverless technologies was often framed around current automated features in trucks. Typical responses, highlighted the benefit of cooperative adaptive cruise control (CACC), cameras, and lane departure warning. Furthermore, they perceived new features, such as automated platooning and inter-vehicle communication/cooperation as a positive addition, which could greatly increase safety and make driving less stressful. However, consistent with other studies (Reis et al., 2020; Wang et al., 2019), several participants (21.1%) stated that designated lanes for AGVs and platooning vehicles would accelerate development and adoption in this area. This was seen as particularly important for public acceptance, as it would reduce contact between AGVs and passenger vehicles. These enhancements were also seen as a way to optimise driving, which could both reduce lead time and emissions. Several participants (36.8%) also believe that automated reversing and parking, which is now common in passenger vehicles, would be welcomed on trucks, due to the high risk with reversing trucks.

In terms of transitioning to AGVs, participants had various views. Many (26.4%) saw the benefit of completely automating the whole process, from loading to transportation to unloading. Where others (25.0%) preferred the option of having AGVs, which could also be manually driven. When prompted that hybrid autonomous-manual vehicles would likely be more expensive, 64.7% of participants with experience in purchasing trucks (n=17) said they would pay between 25% and 50% more to allow the vehicles to be driven manually. However, other participants (30.3%) favoured having a fleet made up of both manual trucks and AGVs, due to the added complexities associated with maintaining more advanced vehicles.

The issue of reliance on AGV manufacturers and operators was raised by several participants (17.1%). Their concerns were similar to other modern companies and service operators, as the complexity of technology increases, we may see a consolidation of companies, reducing competition. This is due to the complexity of the vehicles and the move from being predominantly a mechanical machine to a computerised machine. Additionally, a move to more computerised vehicles will continue the trend of reducing the number of companies that can maintain and service vehicles. This will result in fewer choices for the logistics companies, for both purchasing and maintaining vehicles. This would likely result in greater consolidation of the logistics industry, effectively creating an environment where smaller companies cannot compete.

5.1.2. Impact of removing driver

Participants were asked their thoughts regarding the day-to-day role of truck drivers. Common responses were related to driving, staying within driving hours, reversing trailers in narrow lanes. Participant's also discussed activities outside of the vehicle, such as fuelling, securing the load, safety inspection of tractor and trailer units, paperwork (e.g. checking and signing documents), loading/unloading, and low-level maintenance (this can depend on the company). These responses gave insight into the various duties of truck drivers.

The impact of removing the driver and reliance on driverless technology are interrelated. However, the latter was chosen as the most important theme by twice as many participants as the former. Based on an analysis of the transcripts, this seems to be due to the idea that if the technology is proven to work, then the impact of removing the driver will be minimised. This is due to the suggestion that if a driverless vehicle was able to navigate complex environments like a road network, then technology would also be able to replace any activities that drivers currently do. It is important to note that this theme relates to operational issues, while the previous was from a strategic perspective.

In terms of safety, securing the load was highlighted as an important role for the driver. Although, several people may be involved with loading the vehicle, the driver is ultimately responsible for ensuring the load is secure and does not pose a risk while travelling. This not only means checking the load before departing, but also often re-securing or checking the security of the load en route. Therefore, several participants (39.5%) stated that if the driver were replaced, new technology and securing methods would need to be developed to alert the autonomous driving system to any change in the security of the load.

In addition to securing the load, all participants who had experience of long-distance driving (n=14), stated that a key part of their role was to ensure their load and vehicle was protected. This could mean careful consideration of where they park, leaving trailer doors open to show that vehicle was empty, and staying alert while sleeping in the cab.

The frequency and duration that human control is needed during a journey, would also have a large impact on the usefulness of the technology. If a driver is removed from the main driving task but required to intervene for times when the system is unable to control the vehicle, this would quickly negate the benefits of the technology (Adnan et al., 2018). To understand the reliance on drivers and their role in the AGV, with regards to the impact on security, we identified three main areas of concern from participants' responses. These were staying alert (if the vehicle required some input from the driver), dealing with accidents, and theft.

5.1.3. Impact on data sharing and data security

Much of the discussion around data sharing and security was related to the European Union (EU) General Data Protection Regulation (GDPR), which covers data protection and privacy in the EU (Goddard, 2017). It was also understood by some participants (10.5%), that legislation for AVs in certain regions has been announced. This legislation is around sensor data storage for the duration of travel, to support liability, privacy and security concerns with data collection, and cyber-hacking (Talebian and Mishra, 2018; Fagnant and Kockelman, 2015).

Platooning with other company's vehicles was seen as a mutually beneficial situation, which could require the sharing of data. The majority of participants (69.7%) were accepting of the idea of sharing some information with other organisations, including competitors, if it helped meet other goals, such as saving fuel and reducing lead time. However, it was acknowledged that current data sharing is limited, which is supported by previous studies (Carlan et al., 2019).

Participants were asked how they would persuade other companies to share information. Several participants (44.7%) recommended monetary incentives, with some stating efficiency savings would likely encourage companies to work together. Additionally, a few participants (18.4%), believed that the benefit of platooning, in terms of reducing environmental impact, would likely attract tax relief, which would accelerate the adoption of platooning capabilities.

To further optimise the utilisation of AGVs, several participants (17.1%) mentioned how data sharing could be used to reduce backloads. Vehicles returning empty is a common issue, in which collaboration with competitors to form an alliance, could create a competitive advantage, as it could effectively double the utilisation of the fleet. Therefore, as Los et al. (2020) states, information sharing between operators, will ultimately come down to a trade-off between privacy and solution quality.

5.1.4. Impact on reliance of third-party companies

It was clear from participants' responses that standardised platforms need to be established, as well as funding in infrastructure to support the development and implementation of the technology. Furthermore, it was acknowledged that there would need to be a greater reliance on third-party companies and cooperation with other logistics companies. Concerns around privacy, security, and misuse of data were raised, which is in line with other studies (Kockelman et al., 2017).

Vehicle platoons was an example often cited in the context of data sharing, which could see multiple logistics companies, participating in convoys of vehicles for long journeys in order to save fuel and reduce emissions. Several participants (17.1%) stated that if the cost of operating and purchasing AGVs became prohibitively expensive, smaller logistics companies may have no choice but to lease, not just vehicles but all the services required to operate.

A final issue that was raised by several participants (10.5%), was that of software updates. This was discussed in a number of contexts but was generally to do with the issue of a software update being delivered while the vehicle is stationary, or more concerning to participants, while the vehicle is moving. As with mobile phones, AGVs will likely use technology developed by multiple companies, which could lead to making the vehicle operate less efficiently, and potentially disable it altogether (Bagloee et al., 2016).

5.1.5. Impact on safety

Much of the operational discussions around AGVs considered safety. However, in line with other studies (Fröhlich et al., 2018), participants were not overly concerned with the safety of driverless trucks, which did not require human input. Furthermore, it was generally acknowledged that if a vehicle did not have an occupant, it would remove the risk of anyone within the vehicle being hurt. However, this would not be the case if a person were still required to be in the vehicle for servicing reasons or driving parts of the journey. Furthermore, although a driverless vehicle would remove driver error, participants were sceptical on how much it would reduce the severity of an incident external to the AGV, e.g. collision from another vehicle. Several participants (39.5%) were more positive about the impact of safety, with one stating that the industry was seeking to bring fatality rates down to those found in aviation and rail. Several studies have shown that AVs would have the potential to surpass a humans' ability to identify obstacles and travel safely in all weather conditions (Campbell et al., 2010).

The question of liability was often raised in discussions, with several different views on responsibility being put forward. If an operator was needed to either supervise the safety of the vehicle, either onboard or remotely, then it was argued that this person would be ultimately responsible. However, if the system was driverless, requiring no human oversight, then there could be an argument made that whoever developed the technology could be liable. To overcome this issue, one participant suggested that government intervention is needed, to introduce legislation specifically to address AGV ownership and operation, to protect all stakeholders. This is also found by Fagnant and Kockelman (2015), where they state, "a framework for AV liability is largely absent, creating uncertainty in the event of a crash".

5.1.6. Impact on employment

Participants in a management/leadership or operations role were asked what they perceived as more important in their logistics operations, saving time, or reducing driver cost. Although 60.5% of participants said that saving time is more important, they acknowledged the need to cut costs, with 23.7% stating labour cost should be reduced. Interestingly, 76.3% of participants responded positively to savings in labour cost by reducing the hourly rate of drivers when they are not active, with 23.7% saying it was a possibility, as one participant stated, "potentially, but ideally, drivers would be removed altogether", while another stated, "driver rates will be dependent on the economics and market value at the time; the company will have to pay whatever is required". Although overall participants favoured saving time, they highlighted that the type of load influences lead time, as a participant stated, "this depends on the type of load. For perishables, time is very important. However, wages remain the main costs in transportation". However, 17.1% of participants stated that introducing autonomous trucks would need to provide at least the same amount of cost-saving to that of a driver.

To gain an understanding of the logistics market, all participants were asked if they believe there is a shortage of drivers, and what do they foresee in the future (this question was asked to all participants when the subject of employment was raised and is in addition to the main interview questions). The majority of participants (84.2%) believed there is a shortage of qualified drivers willing to work in the road haulage industry, which will continue to restrict growth. With several (13.2%) connecting the recent increase in shortages, with the possibility of the UK exiting the EU (Brexit) and others (64.5%) linking the continued shortage to demand growth, due to the pressure to reduce lead times in the retail industry. One participant stated, "the UK currently has a large deficit against the number of drivers required, especially on ocean container haulage, which will only get worse in the coming years if Brexit pushes ahead".

In terms of if AGVs would help address the shortage of drivers, participants generally agreed that if a driverless truck could remove the need for a human driver on some journeys, then this would help with driver shortages. However, in terms of overall employment in the sector, the majority (55.3%) believed this would not reduce the number of people employed, at least in the near to medium term. This was due to several factors, including AGVs being used initially only to cope with fluctuations in demand, the likely need that AGVs will still require people to support the vehicles, for tasks such as loading/unloading, and dealing with issues that may arise en route. However, taking a more long-term view, the majority of participants (65.8%) thought there would be an overall negative effect on employment, as the technology improved and was able to complete other non-driving tasks without the assistance of humans. This finding is broadly in line with a study by Gittleman and Monaco (2020), who found that media reports into how autonomous trucks will severely affect the labour force are often exaggerated and do not reflect the reality of the industry. They go on to discuss how reports often take a simplistic view of a truck drivers job as simply being a driving task and overlook the other aspects of the role, which will be harder to replace with automation in the near to medium term.

It was clear from participant responses, that there is a need for a transition period where drivers are trained to conduct various administration roles, operate the AV, and potentially carry out low-level maintenance. Additionally, new operators and supervisor roles would need to be created, to monitor the logistics network, and handle routing and scheduling of the fleet. Although this may cause initial job loss and requires time for industry and the public to adapt to the change as well as accept the technology, the value from long-term benefits is seen as a worthwhile investment by those interviewed in this study. Although initial job loss and public acceptance is seen as a barrier, the key issue remains with the maintenance of the AVs. However, drivers could be trained to do low-level maintenance as part of their new role, or the logistics company could use a third-party provider to issue specialised spare parts and conduct repairs.

Having vehicles that do not need to be driven for some or all of the journey, opens up the possibility for vehicles to be used in different capacities, as when the driver is not in control, they can focus on administrative aspects of their role, resulting in the expansion of the cab space to allow for activities other than driving. However, a study by Fröhlich et al. (2018) showed that truck drivers had generally negative expectations of completing additional tasks during automated driving, as they believed it would make the job more stressful. Although in contrast, they had positive expectations of being able to relax more during autonomous driving. A similar sentiment was expressed by participants with driving experience, who discussed how truck driving would be made more stressful if it was not clear when they would be required to drive, when they would be required to do other tasks, and when they could have a break.

Requiring drivers to complete tasks while in autonomous driving mode, would likely change the interior design of the truck, allowing for more room for the driver to manoeuvre, hence more comfort, particularly during long-haul journeys (Igliński and Babiak, 2017). These changes to driver role may make the job more desirable, in addition to restructuring of working hours, flexibility, and a wider candidate pool would help combat the current shortage in truck drivers. The benefit of AVs for opening up transport to older and disabled people has been identified by several studies (Andersson and Ivehammar, 2019; Harper et al., 2016).

As previously stated, the idea of vehicle platooning was viewed favourably by participants, with expected benefits being made through increased safety and reduced driver stress. Additionally, the impact of automated platooning can be beneficial to driver working hours, especially with long-distance haulage and driver regulations (Larsen et al., 2019). This could happen in various ways, with either all of the vehicles being fully autonomous or the lead vehicle being driven, allowing drivers in following vehicles to take breaks. Further impact on workers could be through prolonging the retirement age, by allowing older drivers to continue working (Zhang et al., 2019). This also impacts the selection of eligible drivers, as it allows a wider category of people with disabilities to be considered.

5.1.7. Impact on direct and indirect fleet costs

For the road freight industry, labour (wages and benefits) is the biggest single cost, at over 43% of total operational costs, followed by fuel at 22%, according to a 2017 American Transportation Research Institute (ATRI) study (Izadi et al., 2020). However, as shown in Table 1, labour costs were the third most discussed cost, after the cost of AGVs and infrastructure. The reason for this seems to be due to the huge unknowns of autonomous technology, in terms of its cost to purchase, operate, and maintain. This meant that discussions were framed around the cost of the technology, with the consensus being that if these costs were higher than manual driven vehicles, then the cost of labour would have to be reduced to make the proposition economically viable.

The majority of participants (92.1%) acknowledged there would be high upfront costs associated with the introduction of AGVs. However, many participants (40.8%) believed these costs would be recouped over time, as they concluded that AGVs, and autonomous technology more broadly, would not be introduced, until there was a strong business case, so that any investment would not significantly impact the business. It was also discussed that AGVs would offer far greater flexibility, which would allow for individual vehicles to be operated more strategically and react to shifts in demand, which could reduce lead time, increase the number of goods delivered, and potentially open up new markets. Furthermore, in line with other studies (Igliński and Babiak, 2017), it was thought that savings would come through an increase in fuel economy and emission reductions (to avoid tariffs), from controlled acceleration and platooning. However, it must be acknowledged that other studies have found emissions from AVs, compared to current vehicles, would at best stay the same and would at worst increase (Moriarty and Wang, 2017). These ancillary benefits were seen as a major cost-benefit for introducing AGVs, with the majority of participants (59.2%) stating that savings on fuel and labour costs would not be sufficient on their own to make the service less expensive than current manually driven vehicles. This is at odds with a study by (Engholm et al., 2020), who found that driverless trucks may enable substantial costs savings, with a total cost decrease of between 43%–58% in their optimistic scenario and between 12%–23% in their pessimistic scenario.

Several participants (18.4%) suggested that for their company, it is likely they would not lease or purchase AGVs, but instead, use a third-party solution to manage these vehicles. However, a majority of participants (63.2%) believed that AGVs would be added to their fleet, if the business proposal were justifiable in terms of significant savings, such as through increased efficiency and reduced labour cost. This was exemplified by a participant, who stated that "investment would depend on the whole-life cost of an autonomous truck, not just the initial purchase price". A study by Fagnant and Kockelman (2015), showed that due to economies of scale, technology maturity, and infrastructure requirements, the cost of driverless technology will come down over time, but will remain more expensive than manual alternatives until market penetration reaches 90%. Furthermore, Bösch et al. (2018), suggest this will initially be driven by increasing popularity of electric vehicles and the availability of charging infrastructure, along with advancements in ADAS technology, for both the logistics and passenger automotive sector.

For smaller logistics companies, some participants (26.3%) remarked that introducing an autonomous fleet, might not be practical, due to high start-up costs, labour transition, and implementation time, all of which represent barriers to entry. If there was a push by the government to move to this technology, unless there were financial incentives, additional cost may be passed on to customers, ultimately leading to higher transportation cost. However, several participants (23.7%) believed their company would be willing to absorb the extra cost of implementing new autonomous features in their fleet if the business proposal showed a clear indication of improving scheduling and reducing order cycle time. Furthermore, several participants (21.1%) also saw the prospect of strategically partnering with other logistics companies as favourable, as it could increase negotiating power. This was viewed as a potential option, for not just purchasing/leasing vehicles, but also maintenance, and other operational services.

5.1.8. Impact on lead time

The discussion around lead time was often framed around a consideration of increasing/maintaining both business contracts and revenue/profit. The majority of participants (52.6%) stated that the key benefit of AGVs would be the positive impact to lead time, which would likely be the overall driver for adopting the technology. This is consistent with other studies, however, as shown by Shladover et al. (2012), improvements in terms of congestion and fuel efficiency will be dependent on a larger number of AVs working cooperatively. Furthermore, the literature identified the importance of lead time and delivery scheduling, as more consumers move to online shopping, increasing demand for rapid day delivery (Ponce et al., 2020).

Typical responses on the benefits to lead time was through improved efficiency, scheduling, utilisation of loads. While potential barriers were perceived, due to reduced vehicle speeds to maintain safety, disruption and inaccuracies of communication and positioning systems, general unreliability of the technology, and increased bureaucracy. On this latter point, a few participants (18.4%) stated that for AGVs, there would be a far greater disparity of regulations, compared to manual vehicles, especially for transporting dangerous goods (e.g. flammable liquids, gases, and corrosive substances, which make up 4% of goods lifted domestically in the UK (Department for Transport, 2020a)) or loads that need specialised handling (e.g. livestock, milk, and frozen foods). This may make it relatively more costly to transport some goods, which could see some logistics companies refusing to transport certain goods.

A few participants (9.2%) discussed the importance of optimising turn-around delivery times. As one participant stated, "a key consideration for AVs is when to engage the technology in order to maximise the benefit". For some participants (15.8%), this meant for standard demand deliveries, while others (17.1 %) believed the priority would be to optimise routes to reduce lead time. Another popular opinion was for autonomous technology to be applied to supplement drivers during peak demand, as one participant stated, "have an autonomous fleet for standard demand and supplement with drivers in peak". Other participants (14.5%) favoured improving scheduling and alliance with other logistics companies equally and favouring the use of flexible autonomous trucks with backload monitoring algorithms.

In terms of vehicle speeds, the majority of participants (81.6%) believed that AGVs would travel significantly slower than manual vehicles, in order to reduce risk, although they would be able to operate for more hours than a manual driver. However, they would likely not be able to make up time if there were travel delays or issues with loading/unloading. To maintain schedules, one participant suggested that "a potential solution to this, would be to deliberately slow vehicles, for some or all of the journey, to allow for increased speeds later in the event of an unavoidable delay". Additionally, AGVs would be required to operate well within the law, adhering to all rules of the road. This would include where vehicles could park, to load and unload. This may cause an issue for light goods vehicles, which are often used to deliver smaller goods door-to-door. This is due to drivers often using their own judgment on where to park, not necessarily abiding by the law, in order to deliver parcels faster. There was also consideration given to the routes AGVs would be able to take, with participants making parallels highlighting difficulties that human drivers have. All participants agreed that AGVs would first be used on motorways and well-maintained roads, with clear lines of sight. The last place AGVs would operate in would be rural areas and places with narrow and badly maintained roads.

5.1.9. Impact on public perception

The main discussion around public perception was based on comparison with media reporting of autonomous passenger vehicle incidents. It was acknowledged that there have been very few AV incidents on public roads in the last few years, compared to manual vehicles. However, media, as well as research and commercial interest, has been highly critical (Xu et al., 2018; Van Brummelen et al., 2018; Bansal et al., 2016; Kyriakidis et al., 2015). The perception from participants was that even if AGVs were proven to be safer and incidents including fatalities decreased, there would still be a high amount of negative coverage if an AV were involved. This is usually found with new innovations, the reputation of the technology is compromised in the event of negative publicity, as was the case with recent Uber autonomous car incidents (Bissell, 2018). Therefore, as one participant stated, "companies would need to have crisis management in place, to prepare the proper response for when things go wrong, in order to control the public narrative".

Participant responses around the environmental impact of road haulage centred around both public perception and government policy. Although the majority of participants (64.5%) acknowledged the importance of reducing emissions and protecting the environment, it was generally stated that for a company to be economically viable the primary goal is to stay profitable. Therefore, it is often difficult for logistics companies to make a unilateral decision on reducing the environmental impact if it does not also have a cost-benefit. However, it was acknowledged that public perception was very important for the industry and appropriate government policies, which encourage "greener" practices, implemented fairly across the industry would be of benefit to everyone.

A key impact in deploying an autonomous fleet, is the environmental implications, as autonomous trucks have the ability to drive in an efficient manner that not only reduces the overall wear and tear of the vehicle but also is fuel-efficient. This method reduces the overall carbon footprint and the CO2 tax, which companies are liable. This impact is increased with platooning, due to the aerodynamic flow; the carbon efficiency increases with every vehicle that joins the platoon, with the truck at the front being less efficient and the furthest one back being the most (Zhang et al., 2017). Collectively, a platooning convoy creates an environmentally sustainable impact that is beneficial for logistics companies, as they move towards more long-term sustainable solutions for their operations. However, as one participant stated, "a long platoon of trucks would be challenging for other road users, in entering or exiting motorways". Other studies have highlighted this as a potential threat to other logistics companies, if they are not part of a platooning agreement (Wang et al., 2019; Smith, 2012).

5.2. Key considerations for the introduction of commercial autonomous road haulage

Based on findings from the study, we have identified six key areas that would need to be considered, for a successful introduction of commercial autonomous road haulage. In some cases, these are design considerations, which can be used by technology and infrastructure developers, and in other cases, policy recommendations, which can be used as a guide for policy makers, insurance companies, and transport planning authorities. It is important to note that although this study looks at the perspective from the logistics industry, any policy decisions would have to consider all road users and the impact on the supply chain. Additionally, the majority of findings are also applicable to autonomous passenger vehicles, particularly if they form part of a taxi service. The key differentiators between trucks and passenger vehicles are they could be operated with no-onboard people, they can be used to transport heavy and dangerous goods, journeys are generally more time-sensitive, journeys can be made up of national and international travel. There are also key differences in public perception, government support, and standardisation between vehicles operated by private individuals and those operated by companies.

The six key considerations we have formulated, consider both how to remove barriers, which could prevent the uptake of AGVs, and incentives, which could lead to accelerated adoption. All considerations are based on the responses from the semi-structured interviews and supported by the literature where possible.

1. **Standardisation**: To maximise the benefits of AGVs, it will be essential to orchestrate the movement of vehicles on both a global and local level. This will mean both communicating to a central system for route optimisation and at a local level for functions such as platooning. This was confirmed by participants, who highlighted the importance of standardisation in the logistics industry. Therefore, to achieve this there will need to be several agreed AV operating standards, in both messaging and mechanism. This was also identified by Fagnant and Kockelman (2015), who highlighted the need for AV operator licences and certification standards.
2. **Hybrid AGVs**: Based on the interview data, it is clear that most participants were not in favour of completely removing the driver in all situations. This was due to issues around loading/unloading and responding to events that an AV could not manage. However, a vehicle that could be switched between fully autonomous and manually driven, was seen as a clear benefit to the industry. These hybrid vehicles would allow greater flexibility and likely support a larger workforce. However, these vehicles would be significantly more expensive than current vehicles. Therefore, as suggested by Scherr et al. (2019), in the near to medium term, mixed fleets will be required, made up of manual and autonomous vehicle types.
   The main reason for wanting to maintain manual control, as highlighted by the interviews, was due to limited confidence in the technology. This perception was not in respect to the safety of the vehicle but being able to operate on all roads and in all weather conditions. Additionally, several participants expressed a fear that AGVs will be reliant on external technology and infrastructure. Therefore, if in the future this technology was changed/removed, a subsequent usage cost was applied, or there were compatibility issues after software updates, their vehicles could stop functioning. This sentiment is similar to the current debate on the switch between fully electric trucks and traditional combustion engines. As a result, an emerging compromise is developing in the form of plug-in hybrid electric vehicles (Speranza, 2018). These bring the benefit of reduced emissions, while reducing the issue of range anxiety and the reliance on the charging infrastructure (Ghandriz et al., 2020).
3. **Liability**: Determining who is at fault when an incident occurs involving an AGV, will be considerably more difficult than with a manual vehicle (Hevelke and Nida-Rümelin, 2015). It will also receive wider media coverage, which could lead to reputational damage for all involved with the operation of the vehicle, whether they were at fault or not. This is important, as public acceptance will be a strong factor in shaping policy (Lee et al., 2018). The complexity of liability is due to the number of parties that would likely be involved with the operation of an AGV (Skeete, 2018). With a manual vehicle, the driver is responsible for the driving task, using their senses and body to control the vehicle. However, for an AGV there will be technology on-board (e.g. lidar, cameras) and off-board (satellite navigation, wireless communication, infrastructure sensors), which will provide input to the control system, all of these systems could be accidentally or deliberately affected, leading to a greater chance of an undesirable control state for the vehicle. Based on the responses from participants, we would suggest that a typical future business structure will need to involve several stakeholders responsible for the safe operation of an AGV, including vehicle manufacturers, autonomous system providers, remote operators/supervisors, as well as multiple organisations responsible for off-board infrastructure and technology. Each would need their own liability insurance, which would make attributing the fault of an incident extremely complex.
4. **Technology timeline**: For logistics companies and related stakeholders (e.g. transport authorities), understanding what technology is on the horizon and when it is likely to be commercially available, would greatly help forward planning. Based on our interview findings, no participant had a clear understanding of what autonomous technology was coming in the future, but all stated a desire to be given prior warning before it was introduced. This also includes the realistic operating potential of future on-board devices (e.g. automated lane keeping system (ALKS)), which is often exaggerated when discussing future technology, particularly that which relies on artificial intelligence (Hancock, 2019). It is also essential that technology development is driven by need from the logistics industry and not by what is technically capable, which is to say, avoiding creating

solutions and then looking for problems to solve.

5. **Infrastructure**: There are several issues surrounding the requirements of road infrastructure to support AGVs, which were raised by participants. These include, who will pay for upgrades and supporting technology? how much of the road network will be supported? and who will manage the various parts?. Having a suitable road network to operate on, is arguably the most important factor for the development of AGVs (Nodjomian and Kockelman, 2019). A clear understanding of the requirements and a firm commitment to roll out changes, would likely accelerate development and encourage logistics companies to invest. However, as Lee and Hess (2020) states, it is not clear what future AV infrastructure requirements are, due to lack of understanding about the requirements of an AV to be able to operate in a complex environment. Therefore, it is likely that planners will react to future developments and infrastructure changes will be made gradually, as each new automated feature becomes commercially available (Fraedrich et al., 2019).
6. **Rules of the road**: Before AGVs are deployed, there is a need for a clear set of guidelines or laws on how all road users should operate. As an example of why this is necessary, there is clear evidence that drivers will treat driverless vehicles differently, by taking advantage of protection systems designed to slow vehicles down to avoid collisions (Madigan et al., 2019). It is foreseeable that logistics companies may take advantage of this dominant position, to either preserve the need for manual vehicles, by slowing individual vehicles or as a more sophisticated attack, by artificially slowing or re-routing vehicles that are within their delivery time window. Another example would be platooning, which as this study confirms, is seen as a near term benefit of greater automation. Long platoons of trucks would be challenging for other road users in entering or exiting motorways (Wang et al., 2019; Smith, 2012), which could lead to congestion and a negative impact to other logistic companies excluded from the platoon.

The move to greater automation in the logistics industry will ultimately come down to risk versus reward. Companies will invest in AGVs if there is a clear cost-benefit and the risk from negative media coverage is low. This would mainly be driven by competing companies, as if automation is proven to reduce costs, changes would need to be made to remain competitive. From a government perspective, any new policies to encourage greater automation would be unlikely punitive, as this would risk adversely affecting the supply chain. However, it is likely they would continue to offer tax relief for lower emissions and other incentives, which could drive changes in how vehicles operate. Finally, there are several issues around road infrastructure, such as requirements for AGVs, time frame for implementation, legality, standardisation, and cost, which will ultimately delay the deployment of commercial autonomous road haulage.

6. Conclusions

This paper presents a study of the impact and barriers for the implementation of commercial autonomous road haulage in UK freight operations, from the perspective of experts in the logistics industry. The research involved conducting a series of semi-structured interviews, which were analysed using thematic analysis (TA). Identified themes were subsequently tested with participants, who were asked to rank them based on importance and what they perceived as a positive/negative impact on road haulage logistics in the UK. The objective of the study was to understand what people in the logistics industry thought about autonomous haulage, and what issues can be anticipated with its introduction. This presented a challenge, as participants were being asked to consider technology that does not exist at present. To overcome this, information was given on potential capabilities of AGVs and each question was contextualised to make them relevant to the current state of the logistics industry. Furthermore, the study sought to understand the incentives and disincentives that would aid or hinder the use of the technology. This information was analysed and used to create six key considerations for the introduction of commercial autonomous road haulage, which includes both policy recommendations and design considerations for future vehicles and associated technology and services. These set of considerations have been formulated to demonstrate the key issues identified in the logistics industry, which could inform technology and infrastructure developers, as well as aid policy makers shape future transport decisions.

The literature revealed a significant shortage of qualified truck drivers in both the UK and US, as well as several other countries. This was confirmed from interviews, which found a shortage of drivers as the main threat to company growth. However, although participants generally viewed autonomous trucks as a way to have more vehicles on the road, the majority believed this would not reduce the number of people employed, at least in the near to medium term. This was due to several factors, including using autonomous trucks to cope with fluctuations in demand, and still requiring people to support the vehicles for tasks such as loading/unloading, and dealing with issues that may arise en route. However, taking a more long-term view, participants thought there would be an overall negative effect on employment, as the technology improved and is able to replace people in warehouse roles.

Increased journey time was seen as a significant negative impact, as AGVs are likely to travel slower than normal trucks, due to heightened safety systems. Although, it was acknowledged that AGVs would likely be able to operate for more hours per day than a human driver. However, it still remains a risk this could cause issues with scheduling and flexibility, which would increase lead times. One suggested method to overcome these issues, is by having designated lanes for AGVs, which would support vehicle platooning. This calls for government funding or privatisation initiative in providing lane sensors, resulting in an on-going project of road infrastructure. Therefore, a likely barrier will be implementing legislation, particularly around insurance, ownership, and interpretation of the highway code for AVs. Another prominent barrier is the issue of sharing information on routes, capacity, and lead time, between logistics providers. Although there are benefits of scheduling and route efficiency, companies tend to feel uneasy about sharing information without signed agreement and clear structures around data ownership. Nevertheless, this would aid connectivity between distribution centres and warehouses, creating a logistics network that allows companies to efficiently utilise their fleet. Logistics companies and freight forwarders usually sell unused capacity below cost to ensure the efficiency of their operations, by automating scheduling through internal communication or externally through sharing information with logistics providers. Autonomous scheduling allows utilisation of the autonomous truck technology, to prioritise journeys based on distance and establish a hierarchy system on product type and demand lead time. The foreseen barrier of this implementation is the cost of monitoring the operation, as supervisors would be allocated to track the vehicles and ensure the pre-determined conditions of the hierarchy systems are properly met.

From the literature, it is evident the logistics industry is increasingly investing in automation, with ADAS features, which have traditionally only been available in passenger vehicles, now being fitted to trucks. This move to greater automation is supported by this study, with all participants reporting seeing an increase in automated technology within trucks and other areas of the logistics operations. However, there was a lot of scepticism on the benefits of AGVs, at least in the medium term, with the majority of participants saying they either do not support the introduction of AGVs or were undecided. However, it was acknowledged by most participants that cost would be the driving force behind the adoption of autonomous technology. This is consistent with other disruptive technology/services, such as ride-hailing taxis, which suggests if AGVs, and autonomous technology in general, start to bring down the cost per mile for transporting goods, logistics companies will have no choice but to either adopt the technology or move into other areas, where AGVs are not able to operate, e.g. more complex landscapes or environments.

The findings show that cost is a significant short to medium-term barrier for the introduction of autonomous technology. However, the cost of operating logistics companies, and the broader supply chain, varies around the world. This is mainly due to the difference in the cost of labour, but also tariffs, local geography, and infrastructure. Therefore, it is reasonable to predict that locations where operational costs are relatively high, maybe the best candidates for the introduction of autonomous haulage. Furthermore, as the cost of autonomous technology decreases, through mass production, technical improvements, and adoption, the cost of deploying AGVs will reduce, enabling economic viability in more locations.

Finally, factors such as employee unions, government policy, and public acceptance, may delay adoption. Further research is needed to understand these different competing forces, for both the UK market and worldwide. Therefore, future work will consider the global impact of autonomous road haulage, investigating individual countries readiness levels from both a technical and acceptance-based perspective. This will involve considering how business is conducted in different markets and the effects of low-cost labour, infrastructure, capital subsidies, and regulations, and their impact on commercial adoption of AGVs in these countries.

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Appendix A. Semi-structured interview questions

Background: This research into the issues and barriers of implementing autonomous road haulage, is focusing on level 4 automation (*no driver required for pre-set routes, e.g. motorways and A-roads*) and level 5 automation (*no driver required for any route*). The vehicles considered are power-driven, having at least six wheels and used for the carriage of goods, with a maximum mass exceeding 3.5 tonnes (e.g. commercial truck), as per EU category N2 and N3. An example use case is the movement of goods (long haul or short haul) from a manufacturer's warehouse to a distribution centre.

1. Do you support the introduction of autonomous goods vehicles?
    (a) Can you explain why?
2. What automation features for trucks would improve the logistics operations? (*e.g. platooning technology*)
3. What are the incentives/disincentives to adopting autonomous vehicles? (*can be from any perspective, e.g. employment, public acceptance, sustainability, design, engineering*)
    (a) What would an autonomous vehicles' commercial proposition include for you?
4. Autonomous vehicles are likely to travel more slowly than vehicles with drivers. However, they will be able to travel much longer without stopping. How might this affect how autonomous vehicles would be used? (*can be from any perspective, e.g. employment, public acceptance, sustainability, design, engineering*)
    (a) * What is more important in your logistics operations, saving time or reducing driver cost?
    (b) If the fleet delivers sufficient capacity to meet peak demand, how will logistics companies solve issues of significant unused capacity at other times?
    (c) Would platooning with other companies' trucks be an acceptable option?
    (d) Would trucks carrying dangerous goods/materials be allowed to travel closely together?
5. Will there be a hierarchy of journey types, and if so, how will that hierarchy operate? How can the logistics companies determine the priority for journeys?
    (a) How could logistics companies be persuaded to share data to enable connectivity?
6. What would be the impact of removing drivers on your logistics operation? (*currently drivers have sub-roles in addition to driving, e.g. signing forms, fuelling, loading/unloading*)
    (a) What would be the impact to your company, if drivers were to be removed from the route between depot and destination?
    (b) * Could the hourly rate of drivers be reduced if they are not active? (*The driver may only be required to operate the vehicle for rural areas and last-mile delivery*)
    (c) Would there be any issues with keeping stock on a trailer without a driver, for a long period of time?
7. What do you believe are the barriers for the wide-scale adoption of autonomous haulage, now and in the future? (*can be from any perspective, e.g. employment, public acceptance, sustainability, design, engineering*)
    (a) Please provide any other information you feel would be relevant to the implementation of autonomous road haulage.
8. What incentives should be provided to encourage logistics companies to invest in autonomous trucks?

** Questions asked to only participants in a management/leadership or operations role.*