Autonomous Goods Vehicles for Last-mile Delivery: Evaluation of Impact and Barriers

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Abstract— **For transport logistics, often the most inefficient part of the journey is the route between distribution centre and end customer. This route, referred to as last-mile delivery, generally uses smaller goods vehicles, to deliver low-volumes to multiple destinations. To optimise this process, route planning optimisation software is used, to maximise the number of deliveries a driver can complete in a day. To further optimise this process, companies are starting to test autonomous goods vehicles (AGVs). This paper presents an evaluation of the impact and barriers of AGVs for last-mile delivery in the UK, by conducting a study of people in the logistics industry and experts in autonomous technology. Qualitative analysis is used to identify positive and negative impacts of the introduction of driverless AGVs, and barriers, in terms of government policy and technical restrictions, which could slow down wide-scale adoption. From the results, we find logistics companies are being pressured to reduce lead-times and offer more predictable delivery-times. This is increasing pressure on the workforce, which already has high-turnover and difficulties in recruitment. Therefore, AGVs are considered a solution to a present problem, which is preventing logistics companies growing and achieving delivery targets, driven by public demand.**

I. INTRODUCTION

In the supply chain, last-mile delivery (LMD) is the least efficient stage and contributes a significant amount to total delivery cost. This is leading to innovations in the vehicles' market, such as new engine technologies, autonomous vehicles (AVs), and novel delivery means. In addition to these inefficiencies, is increase consumer demand and an expectation of shorter lead-times. These issues are not only related to logistics, but also a significant urban planning challenge [1]. Due to the increase in online retail and a globalised economy, changes in demand for products from overseas has increased the complexity of logistics and supply chain networks [2] [3]. This increase in variety of goods and the noticeable reduction in product life cycle, as well as limited capacity in warehousing, has led to both inbound and outbound LMD within cities to become increasingly complex for retailers to manage, particularly with growing demand for a fully integrated omni-channel retailing. This shows a trend where LMD are expected to grow, providing critical impact to the efficiency of supply chain and logistics operations [4] [5]. With growing pressure to achieve "net-zero", logistics companies are pushing for solutions where technologies can be used to mitigate LMD's, adding to externalities from congestion and pollution, which have increased recently due to the growth of goods delivery [6]. The vision of reducing externalities and moving towards a net-zero supply chain, contributes to the idea of having smart cities, where development of new LMD is achieved through advancement in information and communications technology and Industry 4.0. To combat issues of externalities and increase in consumer demand, logistics companies are looking at a transport model based on the adoption of automated electric vehicles for LMD that minimises empty backloads and optimises the distance travelled, while meeting shorter lead-times [7].

Several technological micro-delivery methods have been proposed recently, from the use of autonomous drones, to LMD mobile robots, such as those being trialled by companies such as Starship Technologies, Robby, and Amazon [8] [9]. Much of this development is being driven by increase in consumer demand, through e-retail, to find new solutions for meeting shorter lead-times. However, these vehicles are only able to carry approximately 10 kg of goods, therefore their utility and ability to reduce the cost of LMD is unproven.

Although the technology of delivery robots is relatively mature, the operation of mobile robot LMD faces challenges with public traffic and regulation (such as data protection, liability, and security). Hoffmann and Prause [10], analysed and developed a regulatory framework of autonomous delivery robots for parcels, by highlighting legal implications and proposed modes of compliance. Their classification of mobile robots are as cyber-physical systems for Industry 4.0, with machine-to-machine-communication that are self–guided and able to book suitable delivery slots and choose optimal routes. This, according to Joerss et al. [11], puts autonomous technology at the forefront of efficient LMD operations, with several modifications of autonomous technologies dominating LMD, based on available infrastructure, product options, population density, and customer preference (Fig. 1).

AVs are heralded as the solution to many current issues in the logistics industry. By allowing vehicles to be guided without human intervention, greater route optimisation could be achieved, reducing journey times, improving scheduling, and increasing energy efficiency [2]. To narrow the scope, this study will focus on automated driving for LMD, where the driver is not required for some or all of the journey; this corresponds to level 4/5 of the SAE (Society for Automotive Engineering) J3016-2018 "levels of driving automation" [12]. The vehicles considered are road legal but could also run in pedestrian areas if there was suitable space. Finally, the study will only consider vehicles used for carriage of goods, with a maximum mass not exceeding 3.5 tonnes (e.g. pick-up truck, van), as per EU category N1 [13].

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This paper makes contributions to the literature, by presenting findings from a study of the impact and barriers of using AGVs for LMD, in the UK's logistics operations. This is achieved through a series of semi-structured interviews, with experts from the logistics industry. The questions looked at the issues presented by the introduction of autonomous LMD and the incentives and disincentives that may present barriers for commercial adoption. The findings reveal that logistics companies are being pressured to reduce lead-times and offer more predictable delivery-times. This is increasingly putting pressure on the workforce, which already has high-turnover and difficulties in recruitment. Therefore, AGVs are considered a solution to a present problem, which is preventing logistics companies growing and achieving delivery targets, driven by public demand. However, several barriers have been identified that are likely to limit or delay the introduction of the technology, for example, lack of standardisation, government policy, and cost.

A. *Proximity stations and cooperative last-mile delivery*

The proposal of urban consolidation centres (UCC) in the 1970s, was a management strategy to improve LMD, as it is based on a depot close to the city, where goods are being delivered to individual retailers. This reduces congestion, emissions, and introduces transit in specific time windows to reduce externalities [14]. This results in a reduction in miles per delivery, with the increase of delivery time windows, leading to the introduction of multiple proximity stations, to lower the distance travelled by having a high load factor [15]. The strategy of proximity stations, is to fill them during the night, when traffic is low, leading to economic and environmental benefits [16]. With AGVs, the use of both UCC and proximity stations is necessary in LMD logistics operation, in addition to collection points (e.g. parcel lockers), where a system is put in place for storing delivered goods (parcel) until the customer collects them (self-collection points).

Self-collection points have a similar strategy to parcel lockers (electronic or self-service lockers), which have proven to be popular in recent years, due to their strategic locations in residential districts, shopping centres, and central squares. This system has been adopted by many logistics operators, such as DHL for customer deliveries; to send parcels at any time, in addition to several e-retail companies (e.g. Amazon) [17]. This strategy is now used to improve delivery windows for home delivery, with the use of proximity stations and self-collection points [18]. One challenge, as discussed by Wu et al. [19], is how to choose the locations for self-collection points. For this they proposed a methodology for simulating how crowds emerge at certain hours, to determine the optimal location for self-collection points, by considering both the distribution of a company's potential customers and people's gathering pattern in a city. To improve efficiency, Liakos and Delis [20] proposed cooperative LMD, where an alliance between freight companies is formed as a strategy to collaborate on sharing resources and logistics operation, to maximise deliveries and reduce

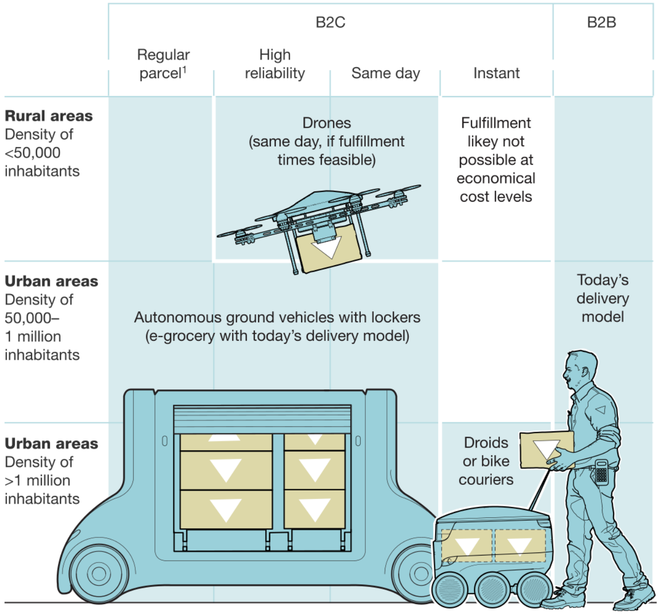

Fig. 1. Available delivery options by density of location. Showing parcel delivery lead-times between next-day delivery standard delivery [11].

empty backloads. Their study proposes the same cooperative LMD strategy for use with AGVs, to allow collaboration on transport and infrastructure, which reduces congestion as well as wear and tear. The collaboration of AGVs can be achieved using an interactive freight pooling service, by sharing AGVs through analysing user-specific requirements, clustering of delivery points, and constructing optimal routes [20]. This strategy minimises total freight distance, which reduces cost. Fagnant and Kockelman [21], noted that AV cost can pose a barrier to many logistics providers, especially if they are SMEs. Although the cost may be reduced with the advancement of the technology, the implementation of AGVs for short journeys will be a gradual process, allowing companies to determine their return on investment (ROI).

The introduction of AGVs for LMD poses challenges for policy makers, as legislation will need to be proposed and uniformed, to allow AVs to undergo road safety certification. This requires clarification on liability between the manufacturer and the logistics service provider. Furthermore, Fagnant and Kockelman [21] stress that without proper policies in place the public perception and acceptance of AVs will cause a negative impact to the implementation of AGVs. Especially with issues surrounding security of the AGVs, their vulnerability to cyber-attacks and issues of privacy especially if data is recorded and stored [22].

II. METHODOLOGY

The study uses semi-structured interviews to evaluate the impact and barriers, which logistics companies face in the commercial implementation of autonomous last-mile delivery. Participants consist of managers from logistics companies, UK government funded projects, and academic institutions, who are experts in the field of autonomous transport. For example, depot supervisors, logistics co-ordinators, operations mangers, directors, programmers, engineers, and academics. Participants are 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. To interpret the semi-structured interviews, a cognitive approach is taken using critical thematic analysis (CTA). 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 a sample size in a qualitative study, is when n should be sufficiently large and varied to elucidate the research aim [23]. The larger the information power a sample holds, the lower n is needed and vice versa [24]. 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 the data collection reaching response saturation. The data collection was completed once responses reached the point at which no new information were being provided by participants. The semi-structured interviews were conducted using a sample of 42 participants from the logistics industry, which was the point the study reached data saturation.

The semi-structured interview questions (Appendix IV-A), encourages participants to reflect on their current knowledge of logistics operations, electric vehicles and LMD, then apply it to a scenario where the last-mile is delivered via AGVs. The proposed LMD logistics operation for AGVs uses electric vehicles, since the transport distances are short. Participants are given a brief description of the different level of autonomy and the scope of the research, which looks at the barriers in the implementation of SAE level 4 and 5 AGVs [12]. The use of CTA takes the approach where codes are built from the acquired data through theme coding. The themes are created from the participants' perspective and interpretation of their comments. The critical aspect of the analysis looks at the patterns generated from the coding, to discover associations in the responses. The use of pattern and theme coding is commonly used in experiential research, as it is not only reliant on word reference, labelling, or assigning codes, but also on the emphasis on describing how item functions vary or depend on external factors, such as externalities. Therefore, CTA is a recognised tool for inductive analysis of qualitative empirical data [25].

III. RESULTS AND DISCUSSION

The themes resulting from the semi-structured interviews were categorised into three dimensions: operating domain; service operations; and cost, based on Ewedairo and Chhetri' model [1]. Using CTA involves first identifying the common issues from participant responses, then allocating codes to the common themes. The study identified several main themes under each dimension (Fig. 2). These main themes arise from asking participants what they perceived as the main barriers for the commercial implementation of AGV for LMD. Questions asked around the "operating domain", resulted in the main themes surrounding impact and barriers of infrastructure and allowed routes for AGVs. The questions asked around "service operations" resulted in two main impact and barrier themes planning and transport. The final dimension of "cost" led to two main impact and barrier themes on labour and technology. The semi-structured interviews further explored these, resulting in several sub-themes. To give context to the CTA, participants responses are quoted, as per Bechhofer and Paterson [26] recommendation, as quotes provide invaluable interpretations.

Under the dimension of "operating domain" and the main theme of "infrastructure", participants found storage facilities to be a barrier. However, although proximity stations could be a mitigating solution, participants noted that an increase of proximity stations must also provide ease of access to the AGV. The barrier was also found in fuelling or battery re-charging stations, as not only do they need to provide ease of access, but also automate the fuelling process, due to the absence of a driver. Furthermore, with the introduction of AGVs, the distribution of fuelling and re-charging stations, would need to consider the distance AGVs can travel. As several participants stated, "the aim is to increase efficiency of LMD, by having the AGV minimise distance travelled, especially on repeated routes". This relates to the other main theme, "allowed routes" for the AGVs. With the use of roads by other drivers, several participants suggested having a designated lane for AGVs, similar to that of public transport (e.g. metros, trams, and buses). Participants factored the rise in shorter lead-time, as more customers choose next-day and preferred delivery times, which would likely lead to AGVs adding to road congestion.

The second dimension, "service operations", has two main themes, the first "planning", consists of sub-themes surrounding security, which are perceived as a barrier to implementation, due to cyber-attacks and leaving goods unattended in the absence of a driver. Another barrier is managing vehicle breakdowns, as in the absence of a driver, there could be issues with reporting the problem and keeping the vehicle safe, until the recovery service arrive. Another issue raised by participants, is if the AGV goes to the wrong location due to a road closure, road works, and re-direction. Although this can be mitigated by using GPS and other location systems, there is still a margin of error to be accounted for in the re-routing of vehicles, which may

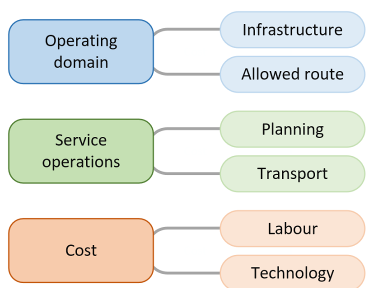

Fig. 2. Critical thematic analysis identified three dimensions and six main themes.

cause delivery delay and longer lead-times. Another barrier to adoption, is the possibility of the AGVs encountering an obstacle and getting stuck. Leading to personnel being sent out to recover the AGVs and set it again on the right rout. As a participant stated, “if a road is blocked due to bad weather, the AGV would be stuck without a driver at the scene”. Participants noted that route optimisation is key, due to the speed limit of AGVs and accounting for location of suitable fuelling and battery re-charging stations. The second main theme “transport” consists of sub-themes surrounding lead-time. As the AGVs would be travelling within the speed limit of the city centre, possibly in designated lanes, several participants considered this could result in a negative impact to scheduling and lead-time. With LMD, logistics companies aim to consolidate customer orders, to maximise deliveries to one area, and minimise lead-time through reducing repeat journeys. Scheduling of AGVs not only need to consider location, lead-time, and routes, but also optimisation of energy usage, to reduce travelling to fuelling or battery re-charging stations. Participants noted that by optimising scheduling, there could be less vehicles on the roads. However, the effects may be reversed with increase consumer demand for online purchases and next day deliveries.

The third dimension of “cost” has two main themes, “labour” and “technology”. For the former, participants noted that issues surrounding loading and unloading goods onto and from the AGV will require labour in the short to medium-term. With possibilities of automating the system in the long term if processes are put in place to have automated warehouses. Although participants stated there might be some long-term labour cost saving, in the short-term, this is outweighed by the cost of requiring labour to load and unload. The introduction of AGVs may result in initial job losses, however, as AGVs will likely require fleet managers and operators to supervise them remotely, participants noted that this will lead to reskilling of the workforce, which would require investment in training. Several issues were noted by the participants, related to the absence of drivers. For example, security of goods being transported, lack of a person to perform minor maintenance, and moving objects that may impede the vehicle. As a participant stated, “drivers can do minor maintenance, like clean sensors or change a tyre”. The second main theme, “technology”, indicates that although participants acknowledge the long-term benefits, there is a cost of short and medium-term investment in purchasing the AGV and associated autonomous technology. This investment also includes cost of service and maintenance. With the cost of new and unproven technology, participants noted the difficulty this may pose to enter the market and be competitive. Participants also acknowledged the cost of automating vehicle docking at charging points, cost of automating the loading/unloading, and the cost of automating the warehouse to cater for the AGVs operation.

To illustrate the findings from CTA, a tornado plot is provided in Fig. 3. The plot shows each sub-theme within each dimension, which are evaluated in terms of positive and negative impact. This CTA is constructed based on participant responses, with each statement linked to one or more themes; each is evaluated as representing either a positive or negative impact, with neutral statements discarded. As the plot shows, operating domain has higher negative impact for proximity and charging stations as well as designated lanes. However, there is a higher relative positive impact on reducing externalities, such as road congestion, due to optimisation of deliveries and routes using proximity stations. The service operations show a high negative impact for breakdowns of AGVs, the planning of loading/unloading, and problems of obstacles or re-direction. The themes with a higher positive impact, are speed-limit restriction, as not only do they make the AGVs appear safer, but lead to scheduling planning to optimise deliveries, reducing lead-time, and efficient use of proximity stations through route optimisation. The use of AGVs lead to better efficiencies of energy use, as the automated systems drives with the speed-limit, as well as reducing wear and tear. The cost dimension shows a high negative impact for the cost of having labour at loading/unloading facilities, or the cost of investment in automated warehouse facilities suitable for loading/unloading and investment in automated docking for re-charging. The use of autonomous technology leads to higher cost in maintenance, as it might be outsourced due to its specialised nature. However, this leads to a positive impact for training of staff and re-scaling, as logistics companies would need fleet operators to supervise the AGVs operations.

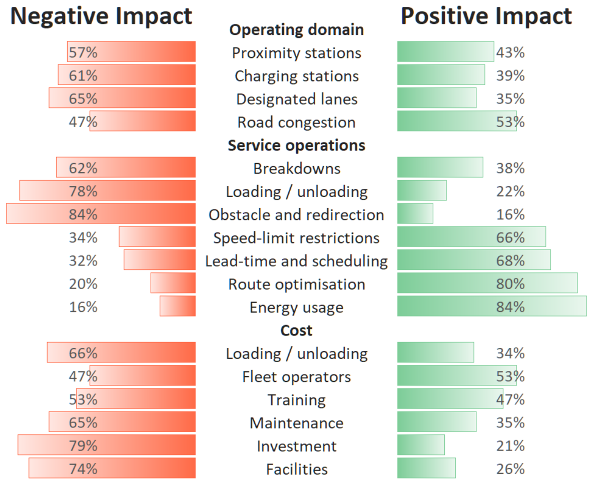

Fig. 3. Identified themes that represent a positive/negative impact on AGVs for LMD. Percentage bar values indicate to what degree the theme was viewed as having a positive or negative impact to the logistics industry.

The tornado plot illustrated themes that pose a positive/negative impact. The results from the CTA further indicates that some themes also pose as barriers to implementation. These are issues surrounding security, due to cyber-attacks, and leaving goods unattended. Further barriers include, the cost of investing in automated storage facilities, the cost of breakdowns, due to minor incidence, where an operator would be required to attend to the AGVs. This also includes issues of AGVs getting stuck, due to obstacles or roadworks that cause re-direction, reducing route opti-

TABLE I

IDENTIFIED POTENTIAL WITH AGVS RELATIVE TO TRADITIONAL VEHICLES

Cost of new and unproven technology
Designated lanes
Cost of automating vehicle docking at charging points and loading/unloading
Impact on scheduling due to speed limit of AGVs
Cost of service and maintenance
Location of suitable fuelling and battery re-charging stations
Cost of automating the warehouse to cater for the AGVs operation

TABLE II

IDENTIFIED POTENTIAL ISSUES WITH AGVS NOT HAVING A DRIVER

No driver to re-fuel/re-charge vehicle
Security (as goods are unattended)
Encountering an obstacle and getting stuck
issues surrounding loading and unloading goods
Increase amount of skilled labour as operators to maintain AGVs
Requirement for supervisors to monitor and manage the AGV fleet
Absence of driver to perform minor maintenance (e.g. change wheel, clean sensors)

misation. The initial cost of investment in staff training, re-scaling, and cost of new technology, poses a financial barrier to companies, especially as ROI is uncertain. In a highly competitive market, the business case, and ROI would need to be quantified for logistics companies to justify investment.

Further from the CTA, the themes that indicate barriers to implementing AGVs commercially, can be divided into two categories: potential issues with AGVs in comparison to traditional vehicles (Table I), and issues with not having a driver (Table II).

AGVs will be able to continually optimise their route, depending on current operating conditions. This could be based on real-time global information about road network performance, or on local information, by observing traffic conditions around the vehicle. This could result in AGVs replanning their route while approaching a junction. Through continual optimisation, AGVs will be able to improve fuel efficiency, which in turn could reduce environmental impact; reduce congestion, by strategically distributing the fleet across the road network [27]; and reduce delivery times or improve scheduled arrival times. However, these benefits assume the vehicle operates as intended and does not get delayed or stuck. This later issue is likely to be one of the biggest challenges for driverless vehicles, as something minor, such as a tree branch blocking the vehicle's path, could easily be moved if a person were present. This could result in the vehicle either having to wait for human assistance or having to alter its route. Other potential issues, which could prevent an AGV operating, include obscured signposts; weather conditions; loss of connectivity; other vehicles; human attacks; major and minor accidents; and internal faults. However, overtime it is likely strategies will be developed to mitigate these issues and the cost/risk benefit of driverless over human-driven vehicles may start to favour greater automation.

IV. CONCLUSIONS

This paper presents a study of the impact and barriers for the introduction of AGVs for last-mile delivery in the UK. The study focuses on vehicles used for the carriage of goods with a maximum mass not exceeding 3.5 tonnes. Findings from a series of semi-structured interviews, with experts from the logistics industry, are presented and CTA is used to identify key issues. To inform the study, first a review of the literature was conducted, which was combined with consultation with experts of AV technology and logistics, to inform a series of semi-structured interviews. The objective of the study was to understand what people in the logistics industry thought about AGVs and to identify potential issues with its introduction. Furthermore, the study sought to understand the incentives and disincentives that would aid or hinder the use of the technology.

Participant responses were analysed using CTA, which identified three dimensions (operating domain, service operations, and cost), each with two main themes. This was further divided into 28 sub-themes, each representing a specific positive/negative impact or barrier. Several of these themes are explored in more detail and conclusions drawn on the level of impact and potential mitigation.

Findings show there are significant barriers to the introduction of AGVs for last-mile delivery. The main issue identified from the interviews, was the lack of unambiguous information about the capabilities of autonomous technology and what infrastructure changes would be required. Furthermore, participants raised issues around the impact of removing the driver from the vehicle, in terms of loading / unloading, fuelling, and assisting the vehicle if it was prevented from moving. However, although there are clearly several unknowns, participants were supportive in general, with many seeing AGVs as a way to enhance delivery optimisation and provide opportunities to upskill the workforce.

This study is part of a larger project, looking at the impact of AV technology across the supply chain. Therefore, future work will investigate how this technology will affect long haul journeys and what the impact would be on the size and location of distribution centres. Finally, the aim of this project is to develop several policy recommendations, which would present a road map for the introduction of AGVs, based on consultation with logistics companies and experts in autonomous technology.

APPENDIX

A. Semi-structured interview questions

Background: This study is investigating the impact and barriers of implementing autonomous vehicles for last-mile delivery. The level of vehicle automation considered is, level 4 automation (no driver required for pre-set routes) and level 5 automation (no driver required for any route).

1) What vehicle automation features would improve the logistics operations? (*e.g. platooning technology*)

2) What are the incentives/disincentives to adopting autonomous vehicles? (*can be from any perspective, e.g. public acceptance, sustainability, design, human factors, engineering*)
    a) What would an autonomous vehicles' commercial proposition include for you?
3) 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. public acceptance, sustainability, design, human factors, engineering*)
    a) If the fleet has capacity to meet peak demand, how will logistics companies solve issues of significant unused capacity at other times?
    b) Would platooning with other companies' vehicles be an acceptable option?
    c) Would vehicles carrying dangerous goods/materials be allowed to travel together?
4) 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?
5) What would be the impact of removing drivers to 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) Would you reduce the hourly rate of drivers if they are not active? (*The driver may only be required to operate the vehicle for rural lanes and last-mile delivery*)
    c) Would there be issues with keeping stock on a trailer without a driver, for a long period of time?
6) What do you believe are the barriers for the wide-scale adoption of autonomous goods vehicles, now and in the future? (*can be from any perspective, e.g. public acceptance, sustainability, design, human factors, engineering*)
    a) Please provide any other information you feel would be relevant to the implementation of autonomous vehicles for last-mile delivery.

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