Deployment of Automated Trucking: Challenges and Opportunities

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Abstract Based on the outcomes from the automated trucking breakout session at the 2017 Automated Vehicles Symposium, this Chapter reviews the current state-of-the-art of automated trucking applications and discusses key factors expected to influence their deployment. It is suggested that a key challenge for the deployment of automation in the trucking domain is that the business models are typically linked to specific and strongly heterogeneous transport operations, each of which associated with a specific set of deployment factors. To handle this complexity, strategic partnerships are expected to be formed between stakeholders, where business models and other deployment factors can be addressed jointly, and in a step-wise fashion, for specific automated trucking operations.

Keywords Trucking · Automation · State-of-the-art · Deployment Platooning · Highway automation · Business models · Safety assurance regulation Public acceptance and trust · Automation impacts on labor

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1 Introduction

The automation of on-road trucking operations is a currently hot topic. Whereas automated trucking is already a reality in off-road application domains such as mining, commercially available on-road automation applications for trucks are still largely limited to lower-level automation functions such as adaptive cruise control (ACC). However, automated driving technologies are developing at a rapid pace and a range of more advanced automated trucking applications have recently been developed and demonstrated on public roads including platooning, exit-to-exit highway automation, traffic jam assist, automated trailer backing and parcel delivery automation. The potential safety improvements, emission reductions and cost savings associated with these applications have created a strong interest from key stakeholders including the trucking industry and their shipping clients, traditional truck manufacturers, new tech companies supported by venture capital, as well as federal and state-level transportation authorities. While technological challenges certainly remain for the higher levels of automation, many of the key hurdles for large-scale deployment of automated trucks with lower levels of automation on public roads are related to non-technical issues such as business models, organizational implementation issues, regulation and attitudes among the general public towards automated trucks.

The general objective of this Chapter is to review the current state of the art in automated trucking technologies and discuss some of the key current deployment challenges and opportunities. The focus is mainly on truck platooning and exit-to-exit highway automation although other types of automated trucking applications are briefly addressed as well. In addition, some lessons learned from the successful deployment of automated trucking in the mining domain are reviewed.

The Chapter is based on the outcomes of the automated trucking breakout session at the Automated Vehicles Symposium, co-sponsored by the National Academies Transportation Research Board (TRB) and the Association of Unmanned Vehicle Systems International (AUVSI), held in San Francisco, July 11–13, 2017 (AVS17). The breakout session included a set of presentations

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providing an overview of the current state-of-the-art of automated trucks and identifying key deployment issues. Two panels with key stakeholders were focused on platooning and highway automation applications respectively, while two deep dive sessions offered the opportunity for more detailed discussion (see the Acknowledgements section below for a full list of contributors to the session). PowerPoint files of most of the presentations are available on the AVS website at http://www.automatedvehiclessymposium.org.

The present Chapter, like the breakout session, focuses mainly on the situation in the US and it should be kept in mind that the deployment of trucking automation technologies may be subject to quite different constraints in other regions such as Europe, China and Japan.

2 Current State-of-the-Art in Automated Trucking

As mentioned above, there is a range of automated trucking technologies and applications. Here we will mainly focus on the two types of applications that have been considered for near-term deployment on public roads: platooning and exit-to-exit highway automation. In addition, we briefly address existing automated trucking applications in off-road domains such as mine hauling, trailer switching, drayage and manufacturing/distribution in dispersed local sites.

2.1 Truck Platooning

Truck platooning refers to two or more trucks driving under coordinated automatic longitudinal control at relatively short following distances. Truck platooning is attractive for several reasons, including energy savings from aerodynamic drafting, more stable vehicle following dynamics, reduced traffic flow disturbances (which has additional savings in energy and emissions) as well as potential safety improvements.

Truck platooning builds on Cooperative ACC (CACC) technologies, which have also been explored for passenger cars. CACC uses vehicle-to-vehicle (V2V) communication/coordination to enable constant time-gap following and ad hoc joining and leaving the platoon. Truck platooning may extend the CACC concept by adding coordination/supervision by the lead truck, a constant clearance distance gap and typically shorter following distances than for CACC. It should be stressed that platooning is not a recent invention but the result of incremental research and development going back at least to the CHAFFEUR EU-funded project [1, 2] in the late 1990s and early 2000s. Recent major initiatives include the FHWA-sponsored Exploratory Advanced Research Program (EARP) projects performed by California PATH [3–6] and Auburn University [7, 8] and the European Truck Platooning Challenge [9].

Platooning functions may be roughly characterized based on the Levels of Automation defined in the Society of Automotive Engineers (SAE) J3016 standard [10]. Level 1 platooning here refers to systems that only automate longitudinal vehicle control (i.e., automatically maintains a constant time gap or clearance distance in the presence of a lead vehicle) while the driver remains in control over lateral control (i.e., steering). There are several recent or ongoing research and development projects on Level 1 platooning such as the UC-Berkeley/California PATH and Auburn University EARP projects mentioned above [3–8]. The startup Peloton Technology, which launched in 2013, participated in a USDOT-sponsored platooning study with Auburn University and have announced plans to deliver commercial systems to customers in 2018. Several truck manufacturers have also announced that they are nearing market introduction of platooning applications in North America although it is not always clear if these will be labelled as SAE Level 1 or 2. Internationally, important platooning field tests are underway or getting started in Australia, Germany, Japan, Netherlands, Singapore, Sweden, and the U.K.

Level 2 platooning adds automatic steering control. Research indicates that this is necessary to enable shorter longitudinal gaps due to visibility limitations for the following driver at shorter distances which makes manual steering difficult [7]. Multiple research projects have tested and demonstrated Level 2 platooning, from CHAUFFEUR [1, 2] to Konvoi [11], SARTRE [12] and Energy ITS [13]. The Texas Transportation Institute is currently working to trial Level 2 platooning in Texas. Several truck manufacturers and tech companies are currently conducting research and development, including public road testing, on Level 2 platooning.

In Level 3 platooning, the driver can divert attention temporarily to other tasks, but is expected to remain available to intervene when needed. Level 4 platooning additionally assumes an ability to ensure achieving a minimal risk condition under any fault condition without any human intervention (while operating within its specified Operational Design Domain, ODD). Level 3–4 platoon followers may also be coupled behind a leader driven at a lower automation level. Operating Level 3–4 platoons places high demands on safety assurance, and many practitioners believe that the current state of the art is currently insufficient to support this level of automation for mixed traffic and highway-speed operations. Thus, in the near term, L3–4 platoons may be limited to enclosed sites such as ports or segregated truck-only lanes to simplify the ODD. However, in Singapore there are plans to implement L4 platooning on public roads [14].

2.2 *Exit-to-Exit Highway Automation*

Besides platooning, the main type of automated trucking use case considered today for near-term deployment is the automation of highway driving operations for individual trucks. While, as mentioned above, Level 1–2 automation already exists in many trucks (e.g., ACC, lane keeping assist and their combination), there is a strong focus today on automating exit-to-exit highway operations at higher levels (Levels 3–4). One particular focus today is on Level 4 systems running driverless on highways, starting and stopping at staging areas adjacent to the highway, with trailers being pulled along local roads by human drivers and then switched to the driverless rigs at the staging area. Prior to 2017, Uber Advanced Technology Group (ATG, formerly Otto) was the only truck automation company focusing on Level 4 driverless operations on highways, while major truck OEMs were pursuing in-house development of Level 1 through Level 3 systems to some degree. However, during 2017 at least five new startups focusing on truck automation emerged in the U.S., with several more overseas, and the major truck manufacturers and suppliers amped up their efforts substantially. Examples of companies focusing on realizing Level 4 exit-to-exit operations, strongly supported by venture capital, include Uber ATG, Waymo, Embark, Starsky Robotics, Tesla and TuSimple. Initial deployments are expected to occur in highly constrained operational environments, such as freeways in remote areas with very little non-truck traffic. Current testing of these systems on public roads has been at Level 2, under the continuous supervision of test drivers.

2.3 Off-Road Trucking Automation

Off-road, confined, areas such as mines, ports and terminals offer more benign environments for deploying automated trucking applications than public roads. This section briefly reviews the successful deployment of automated hauling trucks in mines as well as some examples of other trucking automation applications at local sites such as ports and yards.

2.3.1 Mine Hauling

Mine hauling is perhaps the clearest existing example of successful deployment of highly automated trucks. The automated trucking applications are hauling ore and waste from a loading tool to a crusher for processing or to be dumped as waste. The haul distance range from 2 to 7 miles one way. The vehicle configuration is similar to a two axle on highway dump truck with total gross vehicle weights of 700 ton. Automation of these trucks started with trials in the early 1990s with the second generation of trucks going into production around 2007 with Komatsu and Caterpillar in 2013. The main adopter of these automation applications have been the iron ore mines in Western Australia. Shortage of truck drivers created the pull for mining companies to in this region to be first adopters. The economic benefits of the automation have been made public by Fortescue Metals Group and Rio Tinto. The mining companies are achieving a 20% increase in productivity along with a step change reduction in safety incidents. Over the past few years, the mining companies have been developing their processes and people along with mine layout to optimize the implementation of the automation and they have recently announced plans to roll out the technology to significantly greater number of operations.

2.3.2 Manufacturing/Distribution in Dispersed Local Sites

Level 4 automated trucking development is also targeting low speed operations in and around logistics, intermodal, and distribution centers. This may occur purely on private property, for example container movements in ports, "trailer-switching" between trailer storage yards and loading docks, or on short sections of public road, such as between an intermodal facility (rail, ship port, airport) and a nearby container yard. Because the geographic area of operation is quite small, electric propulsion combined with automated driving is considered as a good option. This in turn is motivating the consideration of completely new vehicle platforms, in some cases with no driver cab. Established industry players are somewhat active in this space, having demonstrated prototype systems. Additionally, one startup, Swedish Einride aims to commercialize a custom-designed electric automated freight platform. The ability to use driverless operations for these short runs on public roads preserves driving time for human drivers hauling other loads.

3 Key Deployment Factors

As reviewed in the previous section there exists today a range of automated trucking applications. However, the extent to which these applications will eventually be deployed on a large scale in revenue-producing on-road operations depends on a number of factors including use cases and business models, safety assurance, human factors, regulation, impact on labor, and public acceptance and trust. This section reviews and discusses a set of key deployment factors that were identified at the AVS17 breakout session.

3.1 Use Cases and Business Models

Key factors affecting the trucking industry today include driver shortage, hours of service, fuel cost, crashes, congestion, sustainability, trailer length/longer combination vehicles and increasing home-delivery parcel volumes. Automated driving technologies have the potential to address all of these factors which is a main reason for the large stakeholder interest. In fact, it is commonly suggested that automated driving technologies will be more rapidly deployed for trucks than for passenger vehicles due to the presence of several strong use cases and associated business models with compelling economic benefits.

The potential benefits of automated trucking depend strongly on the specific use cases considered, that is, what aspects of the trucking operations that are being automated. The trucking domain differs fundamentally from the passenger vehicle domain in terms of the general customer needs (and motivation to pay) for automation as well as in terms of the specific operations that are the focus of the automation. While private vehicle customers' decisions to invest in automated driving features may be related to a desire to increase safety, driving comfort and social status, or freeing up time for work or leisure, the key motivation for a trucking company to invest in automated driving functions is to increase the profit margins on its specific transport operations, although safety is always an important motivation as well. Importantly, trucking operations are strongly heterogeneous so some are more suitable for automation than others.

There seems to be a relatively strong consensus among stakeholders today that the greatest short-term potential for automated trucking is in the context of long-haul freight operations on highways. Compared to urban or suburban roads, highways represent a relatively benign (less complex) environment for implementing automation and long-haul trucks spend the vast majority of their time there. Moreover, for long-haul deliveries between hubs, the operations of several trucks may be coordinated which is particularly important for platooning as it allows for efficient formation of platoons. Thus, large private fleets, with homogeneity in their tractor manufacturer and predictable routes, large truckload carriers and less-than-truckload carriers operating long-haul trucks on fixed routes between terminals are likely to be the main early adopters of automated trucking applications [15, p. 29].

Even given a set of strong use cases, the actual deployment of trucking automation will ultimately depend on the existence of detailed *business models* making a sufficiently strong case for trucking companies to invest in these technologies. A key constraint here is that the trucking industry typically operates on small margins, hence expecting a fast and certain return on investments in new technologies. Moreover, the introduction of automated driving technology may impose the need for other investments such as driver/operator training, additional maintenance, etc. It is important to note, however, that if the efficiency, safety and economic returns from truck automation demonstrated in early tests and simulations are realized, it will be difficult for companies that *do not* deploy automation to remain competitive. This could result in very rapid adoption across the industry.

For Level 1–2 platooning, the key factor driving the business case is fuel savings related to aerodynamic drafting, which increase with reduced distance between trucks [7]. For automation of individual, exit-to-exit, truck operations on highways, major benefits would be expected in terms of productivity, safety and reductions in operational costs. These benefits are obviously highest for higher levels of automation (Level 3+) when the technology can partly or completely replace the driver. However, these operations will also incur significant new costs for the staging areas that will be needed for the transitions between manually driven vehicles on local streets and automated operations on the highway. The challenges associated with safety assurance and public acceptance (further discussed below) have led many stakeholders to the conclusion that large driverless trucks are not likely to be deployed on highly occupied public highways in the near future.

Still, significant benefits may be expected even for lower levels of automation. For example, automating part of the long haul operation may allow for less restrictive hours of service regulations, thus potentially increasing productivity. Moreover, lower-level automated trucking applications are expected to yield significant safety benefits beyond those possible to achieve with traditional collision avoidance systems. These safety benefits translate directly to reductions in operational costs related to crashes (a large part of which are related to litigation issues, at least in the US). It is also likely that automation will bring unanticipated economical benefits. For example in the mining domain, a key motivation for introducing automated trucks was to increase the productivity through increased hours of operation, but is it was also found that significant cost savings were obtained through more predictable operations. This predictability has created significant benefits in the mining value stream in addition to the benefit of increased productivity. In the on-road trucking domain, similar benefits from automation may be obtained by supply chain and logistics providers facing a rise of tight delivery windows with penalties for early or late arrival of goods.

To summarize, deployment of automated trucking features will depend critically on the identification of specific use cases tailored to the needs of individual carriers, and business models promising a significant and fast return on investment.

3.2 Safety Assurance

The safety assurance of automated driving technologies is viewed by all stakeholders as a key deployment factor, especially for higher levels of automation. Brand trust is equally important to vehicle manufacturers, carriers and their shipping clients, so public perception is critical and everyone agrees that safety cannot be compromised for economic savings. The key issue is thus how one can ensure that automated driving applications are safe enough and able to address all the possible edge cases that they may encounter. Indeed, safety assurance turned out to be the most challenging issue in the development of mine hauling automation, accounting for the lion's share of the development costs.

Thus, vehicle manufacturers, suppliers and tech companies need to work together to ensure the safety of automation applications by means of simulation, track tests and on-road field tests. There are also a number of specific safety assurance issues that need to be addressed for platooning, such as how to deal with different braking capabilities of the vehicles in the platoon. There is today a strong focus on the development of novel data collection, testing and simulation methodologies to address these issues.

3.3 Human Factors

There is a range of human factors-related issues that are expected to strongly influence the deployment of trucking automation. These range from the individual driver/operator's understanding of and interaction with the automation, to higher level organizational issues related to the potentially changing roles of the workforce, new decision structures and needs for additional education and training. See [16] for a general overview of human factors issues in automation.

3.4 Regulation

In the US, there is today a patchwork of state laws governing truck operations and automated vehicles. As of January 2018, 21 states have enacted automated vehicle laws and six states have chosen to use executive orders to outline a policy for automated driving. For example, the allowable following distance for trucks is dealt with differently in different states. Hence, increased harmonization is needed, even more so for automated trucks than for passenger cars since trucks are more likely to cross (national and state) borders and are thus susceptible to multiple regulatory frameworks applying to a single trip. However, it should be noted that at least some of these issues (such as differences in minimum allowed following distances) may be possible to solve by technological means (e.g., by adapting the following distances in the platoon when crossing the border).

Current US Federal Motor Vehicle Safety Standards (FMVSS) regulations assume the presence of a driver and may thus be a barrier to novel designs. The House passed a bill in 2017 to increase the FMVSS exemption caps from 2500 units to 100,000 units, which would allow manufacturers to produce novel designs for higher levels of automation, although they would still need to demonstrate that the designs are no less safe than an FMVSS-compliant design. The FMCSA hours of service regulations, security and privacy are other key regulatory areas that may need to be addressed with the emergence of automated trucking.

Existing regulations can accommodate AV technologies up to a point, but this becomes increasingly challenging when moving towards higher levels of automation. Industry generally prefers adapting existing regulations over creating new frameworks locking in a standard that is too high or too low. However, stretching existing regulatory frameworks has its disadvantages and limits and unintended consequences are likely since the regulation was not originally intended for automated trucks.

A recent study [17] has shown that there is considerable potential for a completely new, data-driven, regulatory framework. Current rules and regulations in road freight transport could be replaced by quantifiable policy indicators complemented by the use of data from multiple sources allowing the analysis of stakeholders' alignment with policy objectives and compliance with regulations in near-real time.

3.5 Public Acceptance and Trust

Public acceptance of, and trust in, automated driving technologies remains a key deployment challenge which would be expected to be particularly pronounced for large trucks operating on public roads.

There is general consensus among stakeholders that educational campaigns will be important to foster public acceptance of automated trucking technologies. In particular, it is important to convey a nuanced view and focus on explaining the benefits of AV technologies to the public and openly providing accurate data to support safety claims. Public demonstrations are also seen as good ways to raise public awareness and gain acceptance.

3.6 Impact on Labor

According to the Bureau of Labor Statistics (BLS), there are almost three million truck drivers in the US [18] and there is a worry that trucking automation will create a disruptive loss of jobs in the trucking industry. For example, a recent ITF-OECD Roundtable workshop [19] suggested that job losses in the order of one million people in each of Europe and North America are possible as a result of advanced automated driving technology.

However, at the same time, a major problem in the trucking industry today is the shortage of drivers. Moreover, for reasons discussed above (in particular the challenges associated with safety assurance and public acceptance) many industrial stakeholders do not expect a disruptive introduction of highly automated trucks in the foreseeable future. Hence, these stakeholders argue that automated trucking will most likely not have any dramatic impact on labor, at least not in the short term and with the current generation of drivers. A further reason for this is that large truckload carriers today typically have a turnover rate for drivers of 70–80%. It may be argued that automated driving technologies could offer an improved working environment for drivers in large long haul fleets, thus making the job more attractive and helping to counter driver attrition, as well as attracting a new class of driver in the next generation. Even at higher levels of automation, an operator might still need to be present in the vehicle for, e.g., high-level system supervision, deliveries, or carrying out the manual driving tasks in parts of the network where automated operation is not possible. Clear communication from fleets and vehicle/systems manufacturers on how the deployment of future automated trucking applications is expected to play out will be of key importance for addressing resistance from employees, unions and other associations that may be threatened by these developments.

4 Roads to Deployment

Given the different factors reviewed in the previous section, what is the best approach for moving beyond technology demonstrations towards actual industrial deployment of automated trucking applications?

Based on the discussion at the breakout session, a useful starting point is that what is being automated is not just the trucks themselves but the specific transport *operations* for which the trucks are being used. This is also consistent with lessons learned from the mining domain described earlier. An example of such a specific operation discussed in the breakout session was delivery of refrigerated food items to restaurants. If significant efficiency gains can be realized from automation of hauling, then new food items may be possible to transport due to shorter shipping times and reduction of spoilage. From this perspective, the first step for the manufacturer of an automated trucking application is to understand in detail the specific operations that the automation is intended to address. A key challenge here is that trucking operations are typically heterogeneous and idiosyncratic. In addition, the multitude of factors reviewed above makes deployment of automation a multidimensional problem, where certain issues (e.g., regulation, organizational change) may be critical in some types of operations, for certain types of carriers, but not for others.

Thus, to manage this complexity, it may be suggested that deployment of automated driving functions is best conducted in a stepwise, iterative, fashion, starting with one or a few trucks performing automated operations in revenue-producing conditions. This way, carriers could evaluate specific deployment factors such as potential cost savings, the need for additional investments (e.g., for driver training and education) and safety assurance on a smaller scale and feed back to the own organization as well as to the vehicle/technology manufacturers. Such stepwise, incremental, trials could also be used to foster public acceptance and the data collected could be used as an important input to regulation, particularly in view of data-driven regulatory approaches discussed above.

This further suggests that strategic partnerships between key stakeholders, including carriers, their clients, traditional truck manufacturers, new tech companies and road authorities will become very important for effective deployment of trucking automation applications. These partnerships may potentially also include other players that may add to the business models such as insurance companies.

5 Conclusions

This chapter provided a discussion of current factors influencing the deployment of trucking automation based on the discussions among experts and key stakeholders at the AVS17 trucking automation breakout session. Automated trucking applications have the potential to address many of the key challenges that the trucking industry faces today and there is a very strong interest among different stakeholders, with several new players entering the field.

Off road, closed-course automated trucking applications already exist, in particular for mine hauling and container terminals, and important lessons can be learned from these domains when embarking on trucking automation for public roads. The main current focus for on-road automation applications is on platooning (at different automation levels) and exit-to-exit highway automation.

A number of key deployment issues were discussed. The importance of understanding the specific transport operations and associated use cases and business models for automation was emphasized. Safety assurance (ensuring the automation is able to safely handle all eventualities, or edge cases) is a key constraining factor and human factors issues, including the organizational level, need to be carefully considered. Regulation, in particular harmonization between states and countries, is particularly important for trucking, since trucks are crossing borders more than passenger vehicles. Negative impacts on labor in terms of job loss for truck drivers is often suggested as a major potential societal problem associated with automated trucking. However, stakeholders are divided on how disruptive these effects will actually be. Finally public acceptance of, and trust in, automated trucks is clearly an important prerequisite for large-scale deployment.

Since the return on investment from automation depends critically on the specific type of operations to be automated, it is critical for automated technology manufacturers to know their customers and their specific operations in detail when deploying automated trucking applications. The fact that the significance of the various deployment factors (e.g., safety assurance, human factors, regulation) may differ for different types of automation, and different types of operations makes trucking automation deployment a complex problem and this can be seen as the main reason why the future of automated trucking is so hard to predict. On the other hand, if large scale efficiencies, safety and economic benefits predicted by current trials are realized in operations, there may be a hockey stick adoption of trucking automation since laggards will find themselves uncompetitive in this new environment. These challenges and opportunities are part of what makes the field of automated trucking so fascinating.

It was suggested that, in order to manage this complexity, a likely road to deployment is the formation of strategic partnerships between key stakeholders which can evaluate the business models and address other deployment issues in an incremental fashion, starting out small, but still in a realistic revenue-producing environment.

Perhaps the most important take-away from the AVS17 trucking breakout session is that there seems to be a universal will amongst key players to make automated trucking a reality. However, it remains to be seen how it all will play out in the end and what will be the best way to get there. AVS18 will be held July 9–12, again in San Francisco.

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