Autonomous Driving of Commercial Vehicles within Cordoned Off Terminals

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Abstract: In recent years, the development of autonomous trucks has progressed rapidly. It can be assumed that such vehicles will be ready within the next decade. In order to make use of the advantages of automated driving along the entire transport chain, it is necessary to use the autonomous vehicles on public roads as well as on the terminal areas. The paper presents the extent to which it is possible to adopt autonomously driving trucks to closed terminal areas. Further it discusses the technical, operational and legal requirements for vehicles, transport service providers and terminals involved. Based on the requirements a concept for autonomous driving of commercial vehicles in cordoned off areas is presented. Afterwards this concept is transformed with the current processes on a fully automated container terminal into a concrete example. This example shows how autonomous commercial vehicles can be integrated in the operational processes of an existing terminal.

1 INTRODUCTION

In recent years, the development of Advanced Driver Assistance Systems (ADAS) has progressed at a rapid pace. Such vehicles are expected to offer cost savings, better environmental performance, and higher safety than conventional trucks. In view of increased competition and cost pressure in the transport sector, as well as increased traffic volumes and a simultaneous lack of qualified drivers, it is important to exploit the opportunities arising from the use of autonomous trucks.

At the same time, Automated Guided Vehicles (AGVs) for container transport within closed terminal facilities already represent the state of the art and are used successfully on a growing number of container terminals worldwide. However, these vehicles are not suitable for the use on public roads, since they depend on the infrastructure, consisting of traffic routes and a guidance system. The autonomous vehicles have to travel on public roads to a destination or terminal and transport the goods to the corresponding destination within the depot. Therefore a clear distinction between closed off terminals with AGVs and the public road with trucks is made (see Figure 1). Therefore the reaction on the environment is necessary.

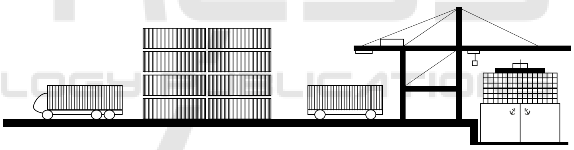

Figure 1: Overview of the distinction of automated vehicles within a port terminal.

In order to use autonomous driving along the entire transport chain, autonomous commercial vehicles have to be integrated into the operational processes on a modern container terminal. The transfer of destination coordinates within the terminal and other information requires communication between the vehicles, infrastructure and transport service provider.

In this paper, Section 2 motivates the use of autonomous commercial vehicles in cordoned-off areas. Section 3 briefly summarizes the state of the art for automated vehicles in terminals and on public roads and subsequently Section 4 presents a concept with corresponding requirements for the operation of autonomous vehicles in closed-off areas. This concept will then be transferred in Section 5 to a fully automated container terminal. Finally, Section 6 concludes with a summary and an outlook on future work.

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2 MOTIVATION FOR AUTONOMOUS DRIVING WITHIN TERMINALS

In the case of commercial vehicles in particular, it is to be expected that new ADAS will offer the possibility of increasing safety on public roads. It is foreseeable that technological progress and the adaptation of the legal framework conditions will make it possible for autonomous vehicles to travel on public roads within the next decades (Fagnant and Kockelman, 2015).

In addition, there is a significant influence on economic efficiency of commercial vehicles (Lauber et al., 2016). On the one hand, personnel costs are a big factor when considering total transportation costs, on the other hand, autonomous vehicles can reduce rest periods and therefore increase driving times. In view of a lack of qualified candidates for the driver's job, there is almost no alternative but to expand the sector of autonomous commercial vehicles in order to guarantee the primary care through freight transport.

Although AGVs are already used in terminals, they are not suitable for the use on public roads. This is because of the strong dependence of AGVs on the infrastructure. They usually have no sensors and act according to the calculations of a central logic, as described in Chapter 3.1. Due to the different conditions on public roads and closed terminals the resulting technical and operational solutions are different for AGVs and autonomous trucks. As the two solutions are not compatible with each other they are spatially separated (see Figure 2). For instance, on the terminals the containers will be transported by AGVs from the quay cranes to a container stack.

Within this area the containers are moved by automated stacking cranes.In order to enable the penetration of autonomous commercial vehicles the haulage yards, service areas and terminals along the transport chain must be prepared for the use of autonomous vehicles. In addition, the requirements of the vehicles must take into account the special conditions of a container terminal, for instance the registration and identification at the entrance of a depot, compared to public roads.

Therefore, this paper examines the use of autonomously driving trucks on public roads and on cordoned off terminals. Further it will examine which technical, operational, and legal requirements must be met by the vehicles, the transport service providers, and terminal infrastructure. The depots and port terminals should be able to use autonomous trucks as soon as industry is able to produce these. The result of this study will be a road-map outlining the necessary future development steps. This information can be taken into account in the development process. In addition, closed-off areas offer the possibility of a test field, as they do not contradict the current legal situation.

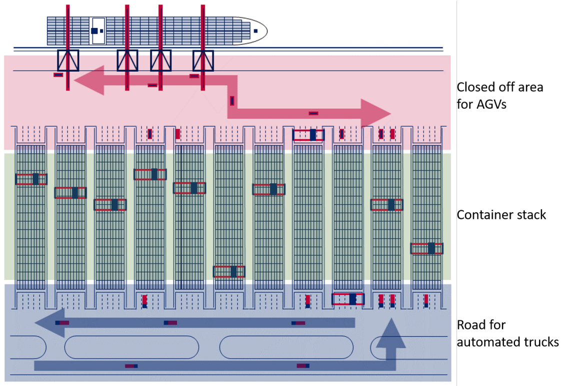

Figure 2: Physical separation of the areas for manual and autonomous vehicles and AGVs.

3 STATE OF THE ART: DRIVERLESS DRIVING

Autonomous vehicles are build for a movement on public roads under various conditions. Therefore they orientate themself within their environment through built-in sensors. On the other hand, AGVs already represent the current state of the art on terminals, without self orientation and build-in sensors. In addition the current implementation of communication systems is presented, because both concepts have a need for a high data transfer rate.

3.1 Automated Guided Vehicles

Automatic vehicles for the transport of containers are currently used in regular operating sequences at various port terminals. For orientation and routing there are no sensors on board of the AGVs or within the infrastructure, but only a possibility for position determination (e.g. via transponders or GNSS) and a communication to a central logical unit (Evers and Koppers, 1996). Due to the lack of on-board sensors an obstacle avoidance is not possible with AGVs.

There are two concepts for the implementation of those facilities. Either it is possible to realize the systems through central traffic control (CT-control) or through distributed traffic control (DT-control). In case of CT-control there is no information processing, neither at the vehicle itself nor within the infrastructure (Evers and Koppers, 1996). The central logical unit keeps track of the vehicle's positions and

Table 1: Comparision between Automated Guided Vehicles and Autonomous Vehicles.

	Automated Guided Vehicle		Autonomous Vehicles
	CT	DT	
sensors	none	short range radar	short range radar, long range radar, optical sensors, lidar, etc
reaction to obstacles	no obstacle detection or reaction	obstacle detection	obstacle detection and avoidance
logic	centralized server	centralized server and on board	on board
routing	centralized server		calculation on board
position	communication via transmitter		dGPS, etc.
communication	required		not required

movements at all times. The routes are calculated completely by the control unit and communicated to the AGVs. Due to the missing sensors on the vehicle, an Automated Guided Vehicle (AGV) realized by CT-control is not able to detect obstacles. Therefore this procedure is not suitable for use on public roads. It is only possible because the AGVs move within a strictly monitored area without access of pedestrians and other vehicles and therefore no incalculable obstacles are present.

By using the concept of DT-control the communication with the AGV is reduced to a minimum. The vehicles and parts of the infrastructure are equipped with control units. The communication between the central unit and the AGV is limited to a suggestion of a route. The vehicle is equipped with short-range radar sensors and has to react to its environment for itself. However, this reactivity consists of the detection of objects and braking, but there is no possibility for obstacle avoidance. After all this option is not suitable for use in areas with several automatic vehicles. The mutual influence complicates the route calculation of the central unit. Therefore this variant also is not suitable for simultaneous use on public roads.

All mentioned properties of both concepts, CT-control and DT-control, are summarized in table 1 for a better overview.

3.2 Autonomous Vehicles

Autonomous vehicles are already being analyzed in the last decades by many research projects and are currently being evaluated by many manufacturers. The feasibility has already been demonstrated in various demonstrations for individual traffic situations. For this purpose, the following should be particularly noted ”Audi Piloted Driving” (Funke et al., 2012) and ”Mercedes-Benz S500 Intelligent-Drive” (Ziegler et al., 2014). Both have already demonstrated the feasibility of autonomous driving using series components in urban and rural areas years ago. But also automotive suppliers like Bosch focusing on autonomous driving within the last decades (Siegle et al., 1992). In addition specialized companies (e. g. Tesla (Tian et al., 2018), Waymo (Bresson et al., 2017)) or data companies like Google (Brown, 2011) started their work on autonomous driving. These vehicles are based on standard technologies (camera, lidar, radar), as they are already used today in trucks and cars. Processing this information by so-called sensor fusion permits precise road holding and obstacle avoidance. (Maurer et al., 2016)

Other institutions in particular the Research Center for Computer Science focuses on the realization and evaluation of novel ADAS. Due to the development of the CoCar these systems and their use can be tested under real environmental conditions. (Forschungszentrum Informatik (FZI), 2019)

Table 1 summarizes the mentioned properties and thus provides an overview of a direct comparison between AGVs and autonomous vehicles.

Although, at the beginning research has focused primarily on autonomous passenger cars the advantages of an autonomously driving truck are obvious. Next to more efficiency, higher safety and networking, and therefore a more sustainable transport chain, economy, society and consumer will benefit equally (Wiesbaden, 2014). With regard to those possibilities the field of research of trucks has increased. In 2014 Daimler was able to cover a longer distance completely autonomously with the ”Future Truck 2015” (Daimler AG, 2014). The basic idea was the bundling and linking of all information and function of current and future assistance systems. Next to the adaptive cruise control function, Stop-and-go and Emergency brake systems, also lane keeping was involved (Brockmann and Schlott, 2015). Furthermore for efficient driving a predictive gearshift program is used. Predictive Powertrain Control provides information about the upcoming road by combining the navigation system and a three-dimensional map (Terwen et al., 2004). Today the research field of autonomous trucks are in no way inferior to passenger cars. A further overview is given by additional literature (Kouchak and Gaffar, 2017). AGVs have the goal to be guided in a cordoned of terminal and autonomous trucks have the goal to drive on public roads. Bringing both technologies together without changing the specific behaviour of AGVs and the trucks is focus of this study.

3.3 Communication Standards

In order to take advantage of autonomous vehicles, traffic telematics systems (Vehicle-to-X (V2X)) enable new assistance functions. Automated driving functions are based on information of the vehicle's sensor systems (camera, radar, lidar, etc.). By connecting these systems, information between vehicles can be exchanged. In order to realize a highly efficient data traffic, the infrastructure e.g. traffic lights, traffic signs and cameras on intersections are connected to the systems as well. For V2X communication, the standards IEEE 802.11p and SAE J2735 have to be supported. However, V2X is not suitable to transmit large amounts of data due to the low bandwidth (DSRC (Dedicated Short Range Communication) Tech Cmte, 2016) and the limited range of 1 km.

Moreover, communication with vehicles is important for fleet management of logistics operators. Existing standards such as SAE J1939 and the fleet management system (FMS) are important factors. This standardized interface enables the installation of customer-specific systems into any vehicle. The transmission of the data to the back-end server is set up via the mobile network (GSM, UMTS, GPRS, LTE, 5G) to connect vehicles at great distances.

4 CONCEPT FOR AUTONOMOUS COMMERCIAL VEHICLES IN RESTRICTED AREAS

As described in Section 3, various solutions have been established for the applications public road and cordoned off terminals. Each adapted to the respective requirements and boundary conditions, but are not compatible with each other. For example, the terminal's IT system is presently not capable of integrating autonomous vehicles as currently developed. Moreover AGVs are unable to drive on public roads.

In order to allow autonomous driving on roads and terminals with the same vehicles, the approach of autonomous vehicles appears to be more suitable. The main reasons are safety, the structural complexity of the infrastructure and the variety sensors installed in autonomous road vehicles. Therefore, we focus our work on the examination of how port terminals can be prepared for the future use of autonomous trucks. In addition to the boundary conditions, the legal aspects have to be considered for setting the concept.

4.1 Technical Requirements

The basic technical realization of autonomous driving of cars and commercial vehicles has already been proven as described in Section 3. Due to the different challenges and boundaries the technical requirements will be divided into three areas (vehicle, infrastructure and communication).

4.1.1 Qualification Profile for Autonomous Vehicles

Any external influences must be taken into account in order to guarantee 24h/7 operation. Those influence occur as weather conditions, differences in incidence of light, but also as failure of system units in the infrastructure. Therefore redundancies with regard to the selection of sensors and passive fallback levels are required for permanent operation. The acquisition of environmental data has to take place with radar sensors and cameras. In addition, traffic signs and changes in the environment must be taken into account. Therefore the longitudinal and lateral dynamics have to be controlled by the autonomous vehicle. Due to autonomous vehicles are already being analyzed by many manufactures, these requirements are considered to be given along with all other assistance systems.

In contrast to the previously mentioned claims, there are requirements specially for the purpose of driving on terminals with operational sequences. One example is the vehicles availability to communicate with the Terminal Operating System (TOS) in order to report that the vehicle has reached a container handover position and is waiting for the landing of the container. Another one is the possibility to un- and lock the ”twist locks” for securing the container on the truck bed. Next to the vehicle, these requirements are also valid to the infrastructure.

4.1.2 Infrastructural Requirements

Due to permission requirements to access the terminal, the identification of the truck is essential. This can either be achieved by using cameras at the parking spaces and at the terminal's entry or via sending and receiving an ID.

This recognition is also crucial during loading and unloading of the trucks. On the one hand the position of the truck during the loading process has to be monitored. On the other hand, it is necessary to check whether the vehicle belongs together with the load and the loads documents. With regard to the loading process and its verification, additional attention should be paid to a high efficiency. The high throughput and the crane position should be taken into account to reduce time losses caused by manoeuvring the vehicles.

The position of the parking space has to be communicated in order to reach the assigned parking position by the truck. This could be achieved by transmitting the GPS data or by route guidance through the infrastructure. Since the truck is designed for driving on public roads it is crucial that the infrastructure is adapted to the road traffic regulations. The given path to the final parking position may therefore be marked only by light signals and traffic signs. This saves further demands on additional functions for routing in the autonomous truck.

4.1.3 Communication Requirements

Communication takes place between all three parties, truck, terminal and operator. The communication between truck and terminal is limited to slot planning and parking position assignment. All further information is communicated to the truck by its forwarding company. The forwarding company communicated with the terminal operator.

For exchanging of loading information from the terminal to the forwarding company a high bandwidth is required. Further the forwarding company have to communicate with the autonomous vehicles, which needs a long range communication. In order to increase the range and bandwidth of the communication the mobile standards LTE and 5G should be supported.

4.2 Legal Aspects

In Europe, the Vienna Convention on Road Traffic imposes a severe restriction on autonomous driving on public roads. It states that a driver must be responsible for the dynamic behavior of the vehicle at all times. In contrast depots and port terminals are cordoned off areas are private property. Therefore, field tests for autonomous driving are moved to these areas. The vehicles comply to general traffic regulations in public road transport, such as light and traffic sights or lane guidance. Furthermore no unforeseen situations, e.g. playing children or other pedestrians, are expected. Thus, cordoned off areas offer the possibility to investigate technical and operational requirements without having to deal with the current legal obstacles.

Commercial vehicles have to find their way independently within port terminals. In addition to self-driving, this also includes finding the allocated parking space and final parking action. This makes it suitable for testing mostly functions without violating the legal framework.

5 EXAMPLE TERMINAL

The concept for the integration of autonomous commercial vehicles has been presented. Within the scope of the study, the project will be applied to a fully automated container terminal in Hamburg (Germany) for the validation. This will be described in the following section.

5.1 Current Operating Sequence

Today, a truck is steered through the terminal by a driver which receives directions from the TOS. This guides the truck through the terminal. Among other information, they contain the control lanes, the transfer position or the customs control zone.

Once the truck reached the assigned parking position at the container storage area the driver has to prepare the trailer and finally report its readiness for container handover. During the handover the drive has to monitor the operation and instantly report any irregularities to the crane operator. After the container handover the driver has to prepare the truck for driving on public road. This includes setting of the twist locks to secure the container on the trailer bed. Figure 3 shows exemplary the different locations on a typical container terminal with a short description and the tasks of the driver at those locations.

In case the container is not lifted from the trailer, but the trailer remains at the terminal the driver has to operate the trailer legs. Before leaving the terminal with a new picked up trailer the driver has to perform a quick check of the trailer's road-worthiness.

Although in most modern container terminals fright documents are already handled electronically, sometimes the driver has to deliver and fetch certain documents.

5.2 Planned Operating Sequence

Obviously, the operating sequence for an autonomous truck differs from the current operation sequence.

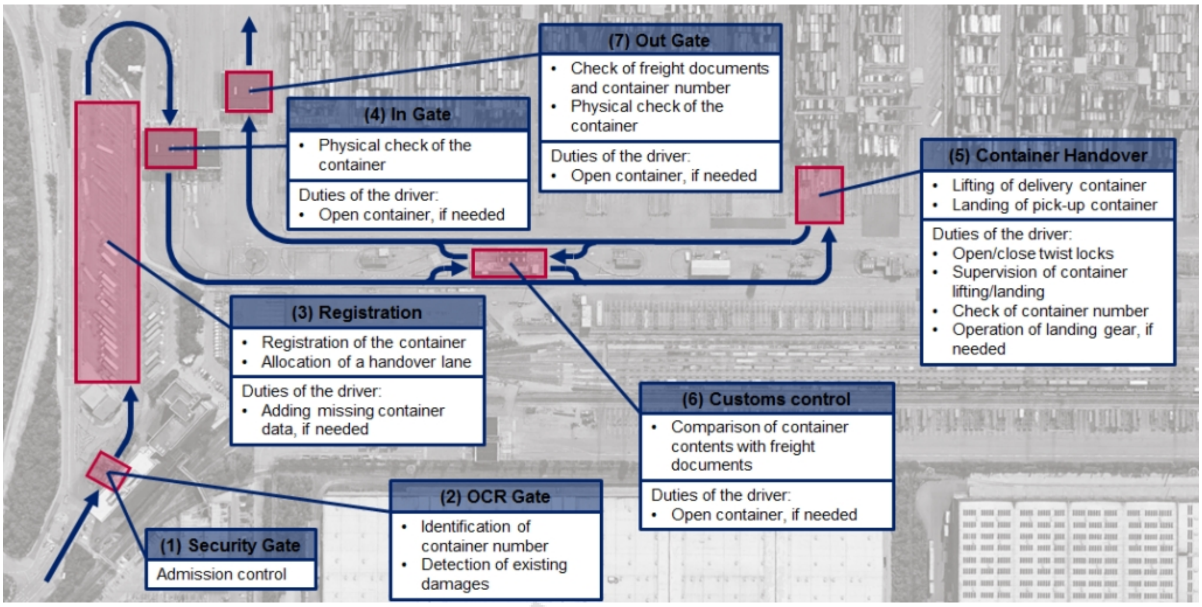

Figure 3: Locations on a container terminal a truck has to call at and the tasks the driver has to perform at those locations.

This is mainly due to the absence of the driver. As a result, all communication with the truck (driving directions, position reports, documents, etc.) has to be done electronically. Since the trucks are build by different manufacturers and forwarding company vary with their telematic system, an common interface supporting all communication is not suitable. Therefore only the forwarding company should communicate with the truck (e. g. route of the truck) and information should be send from the TOS company by a defined communication protocol.

As there is no communication between the truck and the infrastructure, the infrastructure and the terminal operator form a closed system. The autonomous trucks receives the loading and route information from the TOS via its forwarding company and enters the terminal after successful identification. The intended parking position has to be communicated, e.g. by GPS data. From now on the infrastructure only guides the vehicles via public traffic signs and light signals. After reaching the parking position, the crane operator has to be informed of the readiness for loading, for example via the hazard warning light.

To reach the final parking position the self-driving of the truck is sufficient, but in addition to the actual steering, currently the driver also performs further manual tasks as described in Section 5.1. These tasks must either be automated or performed by the terminal personnel. In the first case the automation of supervision of container handover and securing twist locks at the trailer can be done using sensors and robotics. However, the economic and legal implications have to be analyzed in both cases. The driver is currently responsible for securing the load on the bed or opening the trailer for customs, which is then transferred to the terminal operator (including liability). After leaving the terminal the truck drives on public road, as mentioned in the state of the art in Section 3, to the customer depot or other terminals.

In order to guarantee a seamless transition from manual operation to a fully automatic container terminal, the study focuses a step-by-step approach of automation. Therefore all processes on the terminal has to be prepared for an automatic operation, but also for manual operation. This could be achieved by a spatial separation of the handover positions for both kinds of trucks.

6 CONCLUSION

In this paper, a motivation for the advancement of the research for the combination of autonomous commercial vehicles and automated terminals has taken place. Therefore the state of the art in autonomous and automatic vehicles was presented. Since AGVs will not be able to move on public roads, the terminals will have to be prepared for autonomous vehicles as they currently being researched by many manufacturers. For realization, a concept was first presented and subsequently the associated requirement were listed. In addition to the technical demands for the vehicle, the infrastructure and the communication, the legal aspect was addressed too. Finally the concept was applied to a fully automated container terminal for validation. For this reason the current operating sequence was presented and extended to include the planned sequence.

Further steps within this study is a gap analysis. The project investigates the extent to which it is possible to use autonomously driving trucks on public roads and simultaneously on closed terminal areas. Therefore the technical, operational and legal requirements are examined. In addition to the presented demands for the vehicle, the requirements to be met by the transport service providers and the terminals are considered. In the further steps of the study a detailed road map including requirements for autonomous driving in terminals, the feasibility of the concept and the saving potentials will be investigated.

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