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ASSISTED, AUTOMATED AND AUTONOMOUS DRIVING ("TRIPLE A") FOR RAILWAY TRAFFIC

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***Abstract** – Assisted, Automated and Autonomous driving are the terms that dominate discussions not only in the automotive sector but increasingly also in the railway industry. At the Institute of Rail Vehicles and Transport Systems (IFS) of RWTH Aachen University these expressions are summarised with the catch phrase "Triple A". Although these expressions describe similar things, namely the possibilities of using modern communication and information technology to relieve drivers and finally replace them, their precise meaning is different. In this paper an overview on the definitions of the three mentioned expressions is given. Based on that, potential applications and strategies – autonomous, automatic or just assisted – for different areas of rail transport are discussed. In particular the different braking abilities and the different interfaces to other traffic participants lead to diverse proposals on how to achieve driverless or driver assisted operation.*

Keywords – Driver Assistance, Automation, Driverless Operation, Triple-A, Future prospects

1 INTRODUCTION

The International Association of Public Transport (UITP) defines four grades of automation (GoA) for railway traffic [1]. In Fig. 1 they are compared with the SAE definitions that are used by the automotive sector for the automation of cars [2]. The UITP definitions start with GoA 0, meaning driving on sight without any technical train protection, e.g. like a tram running in street traffic. They go up to level GoA 4, meaning fully automatic, unmanned train operation.

At RWTH Aachen University's Institute of Rail Vehicles and Transport Systems (IFS), the term "Triple A" is used to summarise three kinds of digital vehicle operation support:

1.1 Assisted driving

The first A stands for "Assisted Driving", the usage of digital systems to give additional support to the driver of a vehicle. Driver assistance systems are well known within the automotive industry. They help the driver by providing information e.g. about the route (navigation) or about near objects (collision warning). Some assistance systems are also capable of actively interfering with the driver's actions, like parking, lane-keeping or distance control assistance. Although the assistance takes over some actions, the responsibility and final authority is still always up to the driver.

In railway traffic, nearly all European main lines nowadays operate with at least with GoA 1, i.e. signal based and equipped with an automatic train protection system, for example the PZB Indusi system used – amongst others – in Germany, Austria and Serbia. The responsibilities for accelerating and stopping the train as well as control of the passenger doors (which are considered as safety-relevant for trains) lie still with the train driver. Automatic train protection systems are widely used since the first half of the 20th century and are mandatory in most national railway systems.

In GoA 2, or semi-automated driving, the driver only gives the starting signal and supervises the doors. This level is used today in several metro and urban commuter trains with short distances between stops.

1.2 Automated driving

The second A stands for "Automated Driving". From the vehicle's perspective this is still mostly a passive technology. The vehicle is not acting solely by itself but is in most cases controlled extraneous, usually from a central control room. In rail transportation the term "Automated Train Operation ATO" is used.

Driverless operation according to the UITP definition starts with GoA 3, where starting, driving and stopping the train all is done fully automatic. Only the doors still have to be supervised by a human train attendant. This train attendant does not need to be a fully trained driver; however he is still responsible for handling basic train operation in the event of a

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disruption of the automatic systems. The last level, GoA 4, refers to a system without any operational staff on board of the train. Vehicles run fully automatic, operate the passenger doors and are able to react in a safe way in case of disruptions.

Mixed forms of GoA 3 and GoA 4 are implemented in a number of driverless automated metro systems world-wide [3]. While in most cases safe operation is ensured by automatic platform doors that prevent unauthorised access to the tracks, some solutions (e.g. the Nuremberg U-Bahn in Germany) rely on open station platforms with dedicated track bed surveillance systems instead.

1.3 Autonomous driving

The third A finally stands for "Autonomous Driving". In contrast to automated driving this means that a vehicle has to be able to operate without any extraneous control and get all information required for safe operation from its on-board sensors. If necessary, an autonomous vehicle should be able to find its way without external influences and without endangering other traffic participants. While in case of unforeseen disturbances an automated system tends to assume a safe fall-back state (usually standstill in railway systems) until the disturbance is resolved from the outside, an autonomous system – like a human – tries to reach its goals by applying a solution strategy by itself. Therefore for an autonomous system the "intelligence" is on-board, while for an automated system it is centred in a central control entity.

2 DIFFERENCES BETWEEN ROAD AND RAILWAY TRAFFIC

For the automotive industry self-driving, completely autonomous cars are the ultimate goal of current automation development efforts. As this decades-old vision is making huge steps towards becoming reality with today's technology, railway operators like Deutsche Bahn (DB) start to realise the potential of driverless operation for the railway system too and are officially aiming for driverless train operation on main lines in the near future [4].

However, in the opinion of the authors, fully autonomous operation in terms of above definitions, like it would be the case with self-driving cars, is neither reasonable nor necessary for most areas of railway traffic. While the railway industry can gain huge profits by adapting technologies developed by the – much larger – automotive industry in that area, the systematic constraints (and advantages) of guided transport have to be considered.

With regard to "Triple A" the main technical difference between road and rail vehicles is the much longer overall stopping distance of the latter. The overall stopping distance consists of the distance a vehicle covers unbraked during the driver's reaction time and the braking distance that is covered between brake triggering and standstill.

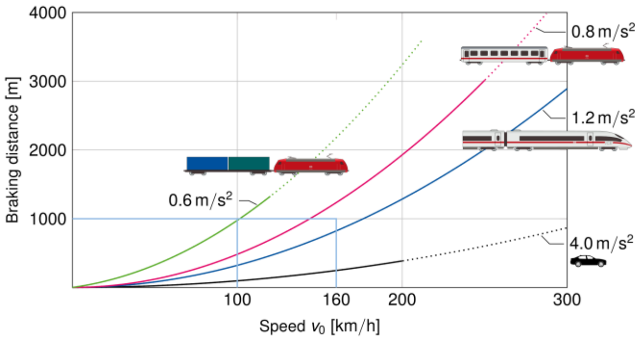

Fig.2. Braking distances for different train categories

While the driver reaction time is vehicle-independent, the physical conditions influencing the braking distance are much more unfavourable for the rail vehicle. One reason is the much lower adhesion coefficient – the relation of normal force and traction/breaking force – between (steel) rail and (steel) wheel compared to a rubber tyre on asphalt road. For brake design usually a rail/wheel adhesion coefficient between 0.1 and 0.15 is assumed, resulting in maximum deceleration values between 1.0 m/s² and 1.5 m/s². For road vehicles, much larger values of 0.4 resp. 4 m/s² can be used. Furthermore the build-up time t_1 between trigger and reaching full braking force can take several seconds on a long freight train with pneumatic brakes.

As an example, in the German railway system a safe stopping distance of 1000 m is assumed for passenger trains travelling at 160 km/h, corresponding to the distance between pre- and main signal. For freight trains, depending on brake equipment and train length, this stopping distance can only be guaranteed for travelling speeds up to 100 km/h or less. High-speed trains can have braking distances up to several

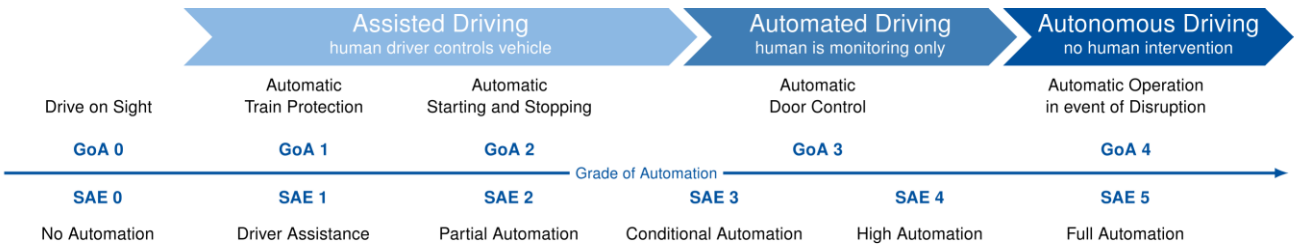

Fig.1. Grades of Automation in railway traffic compared to automotive terms

kilometres. Fig. 2 shows a comparison of overall stopping distances for different train categories, compared to road vehicles.

For "Triple A", this especially means that safe autonomous driving of main-line trains – in the definition of relying only on vehicle-born sensors – is simply not possible with present-day technology due to braking distances far exceeding the line of sight, especially in curves or on crests. This corresponds to the fact that even human driven trains are not "autonomous" like a human driven car, but have to rely on signals and a central interlocking infrastructure to assure a free track ahead. However, the existence of this centralised infrastructure, that already contains information about the whereabouts of all traffic participants, means that – in contrast to road traffic – the goal of driverless operation can already be reached by "merely" automated driving.

3 APPLICATIONS OF "TRIPLE A" FOR RAILWAY TRAFFIC

Depending on the sector of railway operation, several potential applications for different grades of automation arise.

3.1 Main lines

On main lines, assisted driving is already state of the art. Driver assistance systems like the electronic working timetable "EBuLa" used by Deutsche Bahn to continuously display information about the track ahead based on GPS localisation are in common use. Driver assistance systems to support energy optimised driving are also tested successfully and are implemented by several railway operators [5].

Modern systems for automated train protection like the German "Linienzugbeeinflussung" LZB or the European Train Control System ERTMS/ETCS in levels 2 and 3 allow for continuous train control and monitoring of permitted speed. Especially on high-speed lines, when travelling at speeds up to 300 km/h, the danger of missing a conventional track-side signal is too high, so a continuous train protection and speed monitoring system is mandatory. Combined with a cruise control driver assistance system like the German "Automatische Fahr- und Bremssteuerung" AFB, this enables use cases of automated driving. On the predominantly LZB-equipped German main line network it is already common practice that drivers let the AFB system control the speed of the train and – while still responsible for safe operation – confine to monitor the automated systems and the track ahead.

Taking the step towards fully driverless operation on those systems is – from a technical perspective – a very small one. Due to the mentioned braking distances far exceeding the line of sight in most cases, collisions with other trains or objects on the track could not be avoided even by a human driver, so a reliable and trustworthy infrastructure system to ensure collision-free train traffic is already in place. Operating fully automated trains without any on-board track surveillance sensors would therefore – in an undisturbed system – not decrease objective safety. However, such a system would hardly gain acceptance from passengers for whom subjective safety is also very important. The main problem from the technical side is that safe operation in case of disruptions or external influences (e.g. fallen trees on the track) cannot be guaranteed by an automated system.

For the same reasons, fully autonomous train operation on main lines with trains relying only on their own on-board sensors is not feasible with today's infrastructure and technology. The major expected advantages of driverless train operation – less staff cost, improved punctuality and increased safety – can already be reached with automated driving without the need to go autonomous.

For solving the problem of continuous monitoring of hundreds of track kilometres for objects like trees and rocks as well as human or animal intrusion, technologies like "Fibre Optic Sensing" [6], using optical fibres to detect acoustic signatures of those events along the track, are currently tested by railway operators [7].

3.2 Metro and commuter trains

Similar to main line operation, long braking distances combined with very short succession of trains make autonomous commuter trains not feasible. However, due to the mostly closed systems of urban metro subway lines, the technical problem of track surveillance for automated driving is simplified significantly. A growing number of driverless metro systems operating in Grade of Automation 4 already are in operation worldwide [3].

3.3 Marshalling yards

While technically being part of the mainline network, marshalling yards fill a special role. Marshalling yards are places where freight trains are assembled, disassembled or reorganised. While there are some central large "hump yards" with large shunting capacity relying mostly on gravity to move the freight cars, many smaller decentral "flat yards" require dedicated shunting locomotives and a lot of manual work to reorganise trains, making them economically unattractive. Increased personnel costs and dangerous working conditions lead to high potential for automation of marshalling yards.

Since shunting locomotives operate on low speeds and are usually driven on sight, in case of marshalling yards autonomous driving is an interesting option. The fact that shunting locomotives usually stay in the very limited area of the yard can additionally support localised development or testing of an automated or autonomous system. RWTH Aachen University already successfully demonstrated an experimental GPS/Galileo-equipped shunting locomotive that autonomously approached and moved freight wagons ready for coupling [8].

A major obstacle for fully automated marshalling yards is the standard UIC screw coupling used in the European railway system that has to be coupled manually. Currently, no market-ready solution exists to automate the process of splitting and coupling freight wagons. Research on automated coupling robots able to handle standard UIC couplings is still ongoing [9][10].

3.4 Industrial railways

Industrial railways are short, private owned feeder lines for material transport connecting public main lines with factories as well as different loading sites within larger factories. On the factory ground, incoming trains from the main line are usually disassembled and a dedicated locomotive is used to haul single or very few wagons to and from the loading sites, before finally reassembling them to an outgoing train again.

For several reasons, the special conditions of private owned industry railways in combination with high personnel cost and comparatively low throughput in terms of wagon count lead to high automation potential in this area of application. When moving single wagons only between loading sites, the problem of operating couplings between wagons can be circumvented. For locomotives, automated couplings to grab the hook of a single wagon already exist on the market. Low speeds, short distances and a limited rail topology favour autonomous solutions with sensor-based collision avoidance. Finally, legal approval of such systems will be much easier on a confined private rail network than in public.

3.5 Trams

As a special case of rail traffic, trams operate in city centres and mostly run on tracks embedded in the street. They have to share space with other traffic participants like road vehicles and thus are driven on sight.

With increasingly available off-the-shelf solutions for road user assistance systems from the automotive industry, first public transport companies have already started adapting those technologies for trams [11]. As the stated goal of the automotive industry is to develop autonomous and V2X-connected cars able to handle even crowded urban traffic situations, the logical development will be to embed trams into that ecosystem, too.

4 CONCLUSION

The prospects of digitalisation will not spare railway traffic. Completely driverless metro systems are already a reality. On main lines, many things can be done automatically, but not autonomous. However, much still has to be done to increase the acceptance of driverless trains. Only in marshalling yards, industrial railways and tramway systems autonomous driving is feasible. In all cases (further) assistance systems can increase safety, reliability and efficiency of railway traffic.

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