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Operation of Autonomous Tramways

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Introduction

In 2013 sensors from the automotive sector were fitted on tramcars for detection of obstacles on the track for the first time. Since this pioneering test, the technical possibilities have increased nearly exponentially.

That time's advanced driver assistance systems (ADAS) for avoidance of collision were a revolution; today they are reality in daily operation and a requirement in nearly each call for tenders for new vehicles.

The operation of more or less autonomously driving road vehicles (within private traffic or within public transport), which the media follow intensively, has promoted the idea of operation of autonomous tramcars in the sector, at least as a catchword, with projects in Potsdam (Siemens), Karlsruhe (Thales) and Paris (Alstom), which were presented at InnoTrans 2018. At present, projects are also being realised in China (CRRC) and in Russia.

This Position Paper, which has been prepared by members of the Committee on Urban Transport Operation and the Committee on Urban Rail Rolling Stock of the Association of German Transport Companies (VDV), explains the present developments, describes the prospects and lists important points to be defined for the future development.

Present state of the autonomous technology

In 1984 the first automatically driving urban rail system, i.e. the first urban rail vehicle operated without a driver, was put into operation in Dortmund (the so-called "H-Bahn").

In 1994 the People Mover System at the Frankfurt Airport ("SkyLine") followed. Since then, driverless operation has been perfected in many projects, e.g. the Nuremberg metro, and is now international state of the art for independent urban rail systems, i.e. for urban rail systems that are completely separated from road traffic.

In these systems the operation of the vehicles has been automated, i.e. the vehicles are controlled and protected by signal boxes and a safety level of the automatic train control (ATC) system. Often boarding and alighting is controlled by way of platform doors. Otherwise, the platform tracks are monitored. A manned operation centre decides which stored operating programme is to be realised. Thereupon, the train operation is performed automatically (automatic train operation (ATO)). Signal boxes and decentral ATC computers protect the train (automatic train protection (ATP)) and the route by setting the signals. Such a rail system is separated from the other traffic areas by way of e.g. elevation, fencing or a tunnel to ensure that it does not conflict with the surrounding traffic, but it is not monitored by way of sensors. Usually, the functions of relevance to the operational safety have been integrated into the ATP system.

The operation of autonomous rail vehicles on an in-street or segregated track formation can be based on the ATO logic, but there is no signal box logic or ATP logic. Just as a tramcar operated on sight by a driver, the rail vehicle fully depends on its own perception or assessment and therefore it itself also has to monitor the track and assess the situation (autonomously). To fulfil this requirement, it is equipped with either radar sensors, LIDAR (laser) or video cameras (mono or stereo), the signals/data of which are evaluated and assessed in a separate on-board computer.

This approach was introduced in tramcars with the ADAS concept. It was originally described in VDV Report 1520 in 2015 and now the criteria for the planning and verification have been specified in VDV Recommendation 191, which was published in July 2019. The ADAS are partly based on hardware and software from the automotive sector, which have been adapted to rail systems. They can reliably detect obstacles situated directly on the track, assess their relevance in respect of safety and initiate braking. Thus, these ADAS comprise function level 1 of artificial intelligence (AI) for the assessment of events in the vicinity of the vehicle. Since 2017 big vehicle series with ADAS have proved their worth in passenger operation in Frankfurt/Main and The Hague. It seems that they will also be able to detect pedestrians, signals and points in the near future.

On the occasion of InnoTrans 2018 in Berlin Siemens presented an experimental autonomous tramcar in Potsdam. It uses an ATO module for the generation of the power/brake commands. The environment is recognised by ADAS sensors, which have been significantly further developed. Here, too, an AI module is essential for the evaluation of the data collected by the environment sensor system. Both the light rail vehicle in Karlsruhe, which has been equipped by Thales, and the tramcar in Paris, which has been equipped by Alstom, are based on this architecture.

All ongoing pilot projects aim at demonstrating that it is possible to operate an urban rail vehicle autonomously. Passenger operation is not foreseen in these projects. Thus, no project aims at realising boarding and alighting at an urban stop. However, all suppliers believe that it will be technically possible to perform driverless, autonomous shunting operations in the medium term.

At present, all the above-mentioned projects concentrate on the development of a reliable environment detection and interpretation system (comparable with the ATP by automated operation), which should fulfil the safely integrity level (SIL) 3 or 4.

Therefore, the following can be stated as a preliminary interim result:
The available technologies and the ongoing pilot projects contribute significantly to the development of the operation of rail systems, but they will not reach the necessary operational maturity in the near future. Therefore, an autonomously operated, i.e. driverless, tramway is still a long way off and has to be assessed for practicability from case to case.

Concretely, this means that it might indeed be possible and meaningful to operate tramways autonomously if a completely new tramway is set up with insular operation, an independent or segregated track formation and separate station buildings. However, it is doubtful whether it will be possible to operate it within an existing rail system in urban areas, even sometime in the future.

Open points concerning the operation of autonomous tramways

To realise autonomous tramway operation on an in-street track formation in an urban agglomeration, e.g. the following has to be clarified:

— passenger boarding and alighting at urban stops in the traffic area;

— operating procedure by interruption of the operation or by diversion (e.g. point or door fault);

— behaviour of the vehicle if the environment sensor system is damaged in an accident (a tramcar is mostly damaged at its front in an accident, which is the essential area of the vehicle for the environment sensor system);

— operational control and scheduling of autonomous tramcars (e.g. via remote control by the operation centre);

— costs for the vehicle equipment compared to the conventional operation with drivers (initial investment and expenses during the life of the vehicle);

— handling of the availability and obsolescence aspects in consideration of the fact that an autonomous tramcar is equipped with more safety-relevant components (especially in case of the environment sensor system) than a conventional tramcar;

— detection of obstacles reaching the lateral clearances;

— prudent assessment of events by analogy to a driver.

All these open points have not been considered in the field tests performed until now. So far, operating staff of the conventional tramway has to correct faults, especially in case of operational matters. Therefore, it is doubtful whether it will be possible to perform passenger operation without drivers. However, the necessary investments would probably not be justified if autonomous operation were exclusively to be performed in the depot.

Moreover, technical "upgrading" of the tramcar might mean that the tramway loses its position as an efficient and low-cost urban mass transport system, which cannot and shall not be the objective of the development.

Thus, the present state of the "operation of autonomous tramways" can be summed up as follows:

— The technological possibilities have increased considerably, but so far urban tramway operation has not been the objective of an autonomous tramcar project, and often its special features are inadequately considered. At present, (only) what is technically possible is shown. Comprehensive operating concepts do not exist.

— It will not be technically possible to operate a tramway, the lines of which have developed in the course of time, in an urban area without tramcar drivers in the medium term due to the high requirements for detection and assessment of the environment. If a new tramway is to be erected from scratch, the general conditions can be optimised, e.g. by separating the tracks from the private motorised traffic, but as the technology has not been fully developed yet and as operating procedure rules have not been prepared yet, tramcars cannot be operated without drivers at present.

— Operating staff on autonomous trains or platform service staff would reduce the costs for drivers, but in view of the necessary and expensive environment sensor system the cost saving potential is rather uncertain. On the other hand, the fact that it becomes more and more difficult to recruit drivers might support the development of autonomous rail vehicles.

— It has turned out that the necessary environment sensor system is often cost-intensive, complicated, filigree and prone to accidents. Moreover, this system, which originates from the automotive sector, cannot be used in tramcars without adaptations.

— There is no legal framework for the operation of autonomous tramways by analogy to the "Technical Rules for Tramways – Driverless Operation", which applies to independent driverless urban rail systems operated in accordance with the German Federal Regulations on the Construction and Operation of Tramways[1] (BOStrab);

— As the many pilot projects are often very simply described in the media, the general public (and experts) often believe that the present possibilities of operating autonomous tramcars make the operation simpler than it really is and that it can be realised unrealistically fast.

[1] Note: In the German legislation the term "Straßenbahn" (en: tramway) includes nearly all kinds of urban rail systems, e.g. in-street tramways, light rail and metro systems and people mover systems, with the exception of funicular railways.

Prospects and future fields of action

An in-street urban rail system shares the traffic area in the city with the other transport modes like the private car and the public transport bus. Therefore, the fields of action for operation of autonomous tramways cannot be considered out of the context, but only together with the general approaches and developments. Due to its size and its available research and development means the automobile industry will set the roadmap for autonomous driving. The tramway sector has to consider this fact to keep and develop its position as the essential mobility service provider in the urban area in future.

Especially new tramway projects, which include a traffic and urban framework that makes it possible to take advantage of an autonomous operating procedure, e.g. with room for segregated track formations as well as acceleration and prioritising of tramcars and less private motorised traffic, have high implementation potential. Then, a new type of tramway, the autonomous tramway, might emerge.

Autonomous operation might also be interesting to independent rail systems. It might be used as the fall-back level for automated systems in the medium term (first approaches in Chinese metros) or generally for new independent urban rail systems in the long term (e.g. people mover systems at airports).

Driverless shunting in the depot or autonomous turning trips at line terminals might be the first step towards operation of autonomous tramcars within existing urban rail systems operated on in-street track formations in urban agglomerations. Therefore, and because the cost-benefit ratio would be very unfavourable otherwise, it should be possible to realise SIL 3 or SIL 4 environment sensor systems at much lower costs. First experiences in the bus field confirm this assumption.

It is important to further develop the technology for the operation of autonomous tramways. It is essential to consider the following if fast, effective and economic development of this technology is to be realised:

— The single pilot projects should be linked to optimise the collection and evaluation of the extremely broad range of operating data. Industry, operators, science and authorities should join forces.

— A regulatory framework should be prepared so that autonomous tramways cannot only be planned, but also be put into service. It might be possible to use the modifications of the Vienna Convention on Road Traffic, which have been initiated.

— A SIL 3 or SIL 4 environment sensor system should be available at a reasonable price. If possible, it should be derived from a large-scale production in the automotive sector.

— The single tramcars should be interconnected and connected to the surrounding road infrastructure by analogy to the activities in the automotive sector (V2X communication).

— The special requirements for tramway operation have to be observed. Moreover, the efforts should be limited to operational areas that are meaningful from an operational point of view and from a commercial point of view because it is not possible to operate each tramway fully autonomously. It might also sometimes be possible to simplify the operation of future autonomous tramways, e.g. if new urban rail projects are planned appropriately (i.e. with independent or segregated track formations).

— The development of autonomous tramways should be closely coordinated between industry, the operators, science and the authorities under the aegis of the VDV. This approach would also facilitate harmonisation of the communication in this very special subject matter.

— The employees, especially the drivers, shall be involved in the projects. Digitalisation shall not be realised for its own sake.

Conclusion

The VDV finds the new technical possibilities for the tramway sector very interesting. The VDV would like to support the development of autonomous tramways and to actively promote this development with partners from industry, science and authorities.

Further steps have already been agreed upon. Concretely, it has been planned to define, develop and test concrete cases of operation like partially autonomous shunting in depots, which are meaningful from an operational point of view.