Decoupled integration of automation functions for non-productive operation

A concept for the integration of assistance functions into existing vehicles and infrastructure maintaining homologation

Pfaff, Raphael[1], Schmidt, Bernd D.[1], Babilon, Katharina[1]

[1]FH Aachen, Mechanical Engineering and Mechatronics, Aachen, Germany

Abstract

Automation of train operation, frequently aiming on mainline operation, plays an increasingly vital role on the technological roadmap of the railway system. A less addressed topic is the automation of non-productive operations in the railway context, in particular stabling, which do not generate revenue for the railway undertakings and employ scarce personnel during this time. The typical business case is viable, as long as little to no cost arise from the acceptance testing and homologation. The SAMU project presented in this paper aims to develop functionally decoupled interfaces to vehicle and infrastructure, which enable a cost effective refurbishment of such functions.

Keywords: Automatic Train Operation, Stabling, Shunting

1. Introduction

A typical revenue service operation of a passenger multiple unit starts and ends at a dedicated stabling track. From this starting point, the vehicle is powered up and runs through its pre-departure checks before it can be moved to the first platform to start its productive run. The same occurs at the end of a day of operation, here the service ends at a platform, after which the vehicle is brought to a stabling track or a depot.

From the point of view of the driver, the transfers to and from the stabling point are the most inconvenient part of the job: they are typically done late at night or early in the morning and include considerable walking distances in the railway area. From an operators view, the time between stabling and first or last passengers do not contribute to the company revenue, however cause personnel costs as well as occupation for the increasingly scarce resource of railway drivers. The time for moving to and from stabling (including surveillance of the automated start-up and test routines) is estimated to be two to three hours per day, which means that 15% - 20% of the driver’s time and cost is spent on non-productive tasks.

While there is an obvious advantage in automating railway operation as much as possible, it requires substantial investments in infrastructure and rolling stock while at the same time, many issues for mixed operation are not solved yet. At the same time, one major economic factor for railway undertakings is the depreciation of assets which means that it is imperative to run vehicles and infrastructure according to their planned life cycle. Also major upgrades, such as an integration of automatic train operation (ATO) functionalities, are prohibitive due to the cost and risk associated with homologation procedures.

To overcome this issue and solve the problem of automation of some non-productive functions, a decoupled approach that uses existing interfaces to both vehicle and infrastructure appears feasible and does not require new homologation tests.

An automation approach typically requires interfaces to both vehicle and infrastructure as well as a means of communication between both. The vehicle interface needs to be able to control the velocity of the vehicle and command brake applications. The infrastructure interface receives the movement authority and any emergency brake commands. Both interface units rely on safe and available communication, in particular with regards to emergency brake requests.

The Stabling Automation for Multiple Units (SAMU) project aims to develop and demonstrate a concept for the decoupled integration of automation functions into existing fleets, operating on existing infrastructure while the homologation of both subsystems is maintained.

1.1 Problem setting

SAMU aims to solve the problem of automating vehicle driving functions for limited tasks while at the same time maintaining the integrity of the vehicle in such a way that existing homologation a remain valid. This is a valid problem since the multiple unit age distribution (shown in Figure 1) indicates that most multiple will continue to operate for at least ten years, assuming the standard lifetime of 30 years. These vehicles were put into service under different homologation regimes, which makes a new homologation particularly difficult and costly.

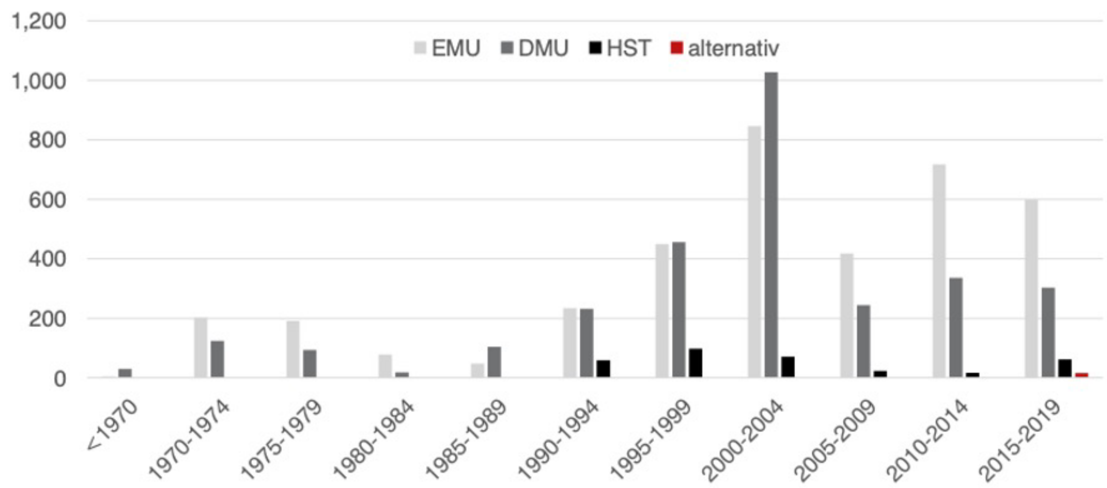

Figure 1: Age structure of multiple units in Germany (2020 data by SCI Verkehr) [1]

1.2 GoA perspective

The standard point of view for ATO classification in railways is the UITP Grade of Automation [2], which focus on urban public transport vehicles. The different Grades of Automation (GoA) are shown in Table 1. It is interesting to note that this definition is applicable mostly to the revenue part of the service, since part of the definition is derived from e.g. door control.

In Table 1, the infrastructure and vehicle requirements are added to the classification. It is obvious that an increase in GoA requires more infrastructure, e.g. in the form of continuous safe communication or localisation, as well as more vehicle borne sensors, e.g. for obstacle detection. Most sidings suitable and available for stabling are equipped to allow shunting movements, which would suffice only for GoA 0. Also vehicles are only equipped to operate in GoA2 at best.

The task in SAMU is to run a GoA4 operation in a very limited scope with a GoA1 vehicle on GoA0 infrastructure. Amendments to the existing equipment are likely to be required. Any addition of e.g. sensors or control units shall be done such that no new homologation of the vehicle is required.

Table 1: GoA classification and technical requirements

Grade of Automation	**Operation type**	**Description**	**Infrastructure and vehicle requirements**
GoA0	On-Sight	No automation, fully reliant on driver.	None
GoA1	Manual	Vehicle operation manual, protection against errors by train protection system, e.g. German PZB.	Low: Most legacy systems provide the functionality.
GoA2	Semi-automatic	Driving functions are automated, mostly relying on an advance train protection system which includes positioning of the train and continuous exchange of commands, e.g. German LZB. A driver in the cab is still responsible to ensure safe passenger transfer, freedom of movement of the vehicle and can take over the control in case of emergency.	Medium: Updated tracks, e.g. in the high-speed network, provide sufficient infrastructure. No special equipment of the vehicles required.
GoA3	Driverless	In addition to driving functions, door operation is also automated which requires no driver in the cab. A member of staff is in the vehicle to take over control of the train in case of emergencies.	High: Track infrastructure as for GoA2. Vehicle equipment has to ensure safety of passengers during boarding and alighting as well as provide obstacle detection means.
GoA4	Unattended	All operations can be performed without staff on train, also in emergency situations.	High: In addition to GoA3 requirements on vehicle and infrastructure, the installation of platform screen doors is recommended.

1.3 Economical perspective

Since driving personnel for railways is currently a scarce resource, the economy of the SAMU system could be calculated against cancelled services which justifies enormous investments. If however, only a conservative saving of 2 h of driver time is calculated, this yields potential savings of 100 €/d and 30.000 €/a. This makes a total investment of 150.000 € per SAMU system economically feasible.

It is obvious that this amount is not sufficient for any homologation process except for large fleet sizes and truly homogeneous stabling requirements.

The SAMU system consists of two vehicle borne units equipped with camera and lidar as well as one interface to the control room. By dividing the estimated investment into three equal parts, a target price of 50.000 € per part of the system can be derived. For this price, many of the sensor technologies currently being tested for automatic railway operation are unavailable [3, 2]. This calls for a robust, yet performant approach.

2. Solution Approach

The SAMU system consists of interface units integrated into both vehicle and control infrastructure and a means of communication between these.

2.1 Vehicle interface

The SAMU vehicle interface receives movement authorisation as well as any emergency stop request and transmits these to the vehicle. In addition to the transfer of information and commands, the vehicle mounted unit also guarantees the freedom of movement. For this purpose, it is equipped with a combination of camera and lidar sensors as well as edge processing capabilities. Since multiple units, the targeted vehicle segment, offer short braking distances from typical shunting velocities, a far less sophisticated sensor equipment and processing is required in comparison to other solutions currently developed.

It is intended to use the multiple traction interface of the vehicle via the coupler for the vehicle control. This typically exposes a wired emergency brake loop as well as traction control to the SAMU system.

2.2 Environment perception

The environment perception system on the one hand needs to allow for sufficiently safe operation, while on the other hand it needs to allow for sufficient performance, typically expressed in terms of velocity for the shunting movement. Since the intended stabling operation will take place under shunting regime, the maximum velocity by regulation is 25 km/h. An in-depth study of braking distances at low velocities is provided in [5].

Since the target sector is multiple units, the deceleration can be expected to be rather constant and at least $a = 0.8\ \mathrm{m/s^2}$. Further the reaction time of multiple unit brake systems is typically well below that of the UIC brake system and for this study assumed to be $t_r = 1$ s. The braking distance from an initial velocity v_0 is thus expressed as

$$s = \frac{v_0^2}{2\,a} + t_r v_0.$$

The braking distance for different initial velocities is shown in Figure 2.

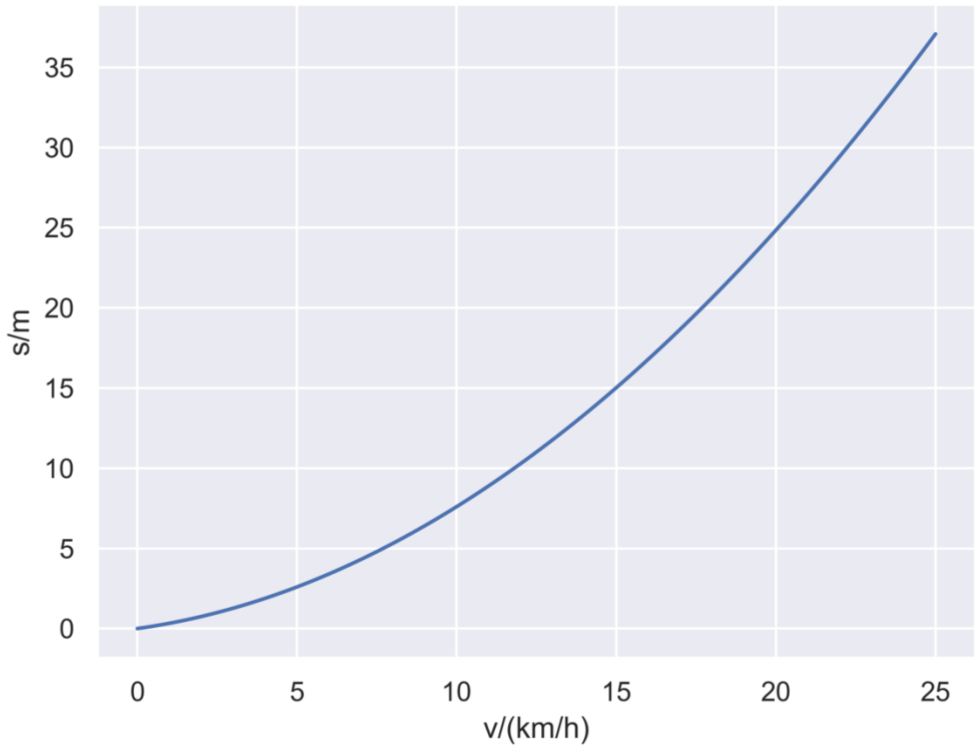

Figure 2: Braking distances for different velocities in the shunting regime

All stopping distances are well within the range of affordable lidar sensors and commercially available cameras are able to detect objects within this range. The perception system can thus be based upon readily available sensors.

For the decision system, the lidar resolution is another critical aspect. It is vital that sufficient points are generated from objects in the trajectory of the train to be moved. By using a MEMS based rather than a rotating lidar, it is possible to scale the resolution while at the same time

2.3 Decision system

The decision system has the task of analysing the planned trajectory for any obstacles that would inhibit driving. The decision whether to go needs to be made such that an accident is avoided. The German standard [6] provides a risk score matrix. For accidents in the shunting context, the requirements are either none in risk category A or 10^{-5}/h for risk category B.

Table 2: Risk categories and example scenarios (selected from [6])

Category	Example scenarios (selected)	Risk
A	• Contact of shunting movemen with object • Untimely emergency brake application	No injuries
B	• Contact of freight train with object • Collision of shunting movements	One minor injury

In current solutions known to the authors, an explicit search for objects, mostly by help of artificial intelligence, is applied to the images supplied by the perception system. While this is an approach closely resembling the human operator, we do not expect that a formal proof of such systems against the requirements mentioned above is possible with appropriate effort. Instead of analysing for objects in the path of the vehicle, the solution already established in the SAMIRA project uses LIDAR scanner information to analyse the free distance ahead of the vehicle.

According to this free distance, the currently possible velocity is selected such that stopping before the end of this free distance is possible. In this way, the decision and velocity selection resembles the concept of moving block operation in mainline more closely.

As indicated in Figure 3, the resolution is high enough to allow for such a procedure for the braking distances shown in Figure 2. In particular, at a conservative detection ration of 99.8% per LiDAR point, objects covered by at least eight points will be detected at a rate of

$$\lambda = 1 - 0.26 \cdot 10^{-6} > 1 - 10^{-5}$$

and will lead to stopping of the vehicle before the object.

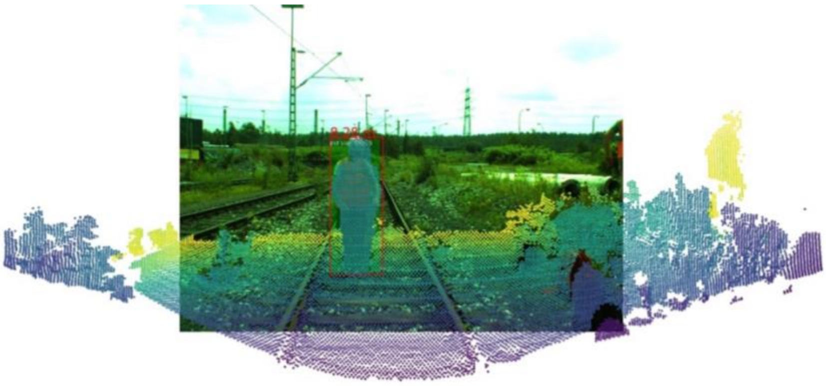

Figure 3: Person in the planned trajectory of a shunting movement (image captured from stationary vehicle)

A remaining problem in this decision algorithm is the track detection. Since most algorithms known to the authors rely on potentially unsafe image processing techniques, a conservative approach is proposed based on the minimum radius in either direction of the vehicle, which are merged in the freedom of movement analysis to form the space required for continuing the movement.

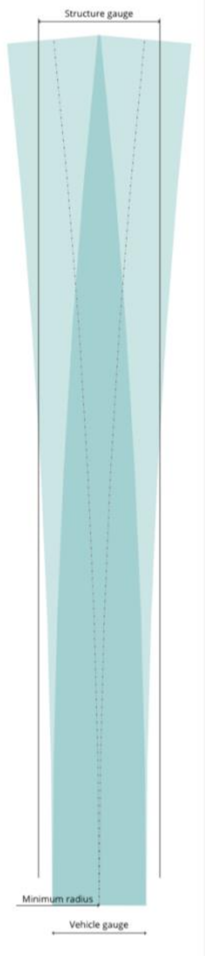

Figure 4: Conservative track position

Such a space is given in Figure 4, which is drawn to scale for a small radius of 50 m. The maximum distance that can be considered free safely is 12.7 m, providing a maximum possible velocity of approximately 10 km/h. The situation improves for a minimum radius of 300 m, which is the standard point radius for German infrastructure. Under this assumption, the maximum free distance that can be detected is 31 m, yielding a maximum velocity of approximately 20 km/h. Both velocities are sufficient for automated shunting operation, since the time constraint is not as vital as it is under human surveillance.

This approach can be considered rather conservative in that it will not provide sufficient braking distance for high velocities unless the radii on the infrastructure are sufficiently large. It may be further improved by adding different radii for different ranges of infrastructure or providing faster or more efficient brakes to the system.

2.4 Infrastructure interface

The SAMU interface to the railway infrastructure is based on a simple concept:

The digital marking of an autonomous shunting area. As the stabling tracks and the platform track are always the same due to the limited size of the station, only a limited amount of trackside elements needs to get evaluated. This tasks are performed in the SAMU lineside electrical cabinet (SAMU-LEC).

It is intended to use existing monitoring contacts or additional current probes of signals and turnouts (PZB-interface, electrical point detector, Sh1-lamp current detector) for this purpose, detecting the shunting route and the given movement authority from the lineside shunting signal. So it is possible to convey the movement authority for shunting to the SAMU system without implementing additional input or outputs to the interlocking system in order to avoid costly software changes and costs for re-certification of the interlocking. In the application scenario selected for this project, three points and two point machine operated track locks need to be traversed in order to move from platform 12 to track 8, depicted as orange line in Figure 5. It may be viable to use a combination of the point machine monitoring contacts to establish the route and lamp current detection of Sh1 signal lamp to detect the movement authority. Since the operation is led on an on-sight basis, it will use the technique proposed in Section 2.3. to select the maximum velocity. In case of an emergency situation, movement authorities may be withdrawn by setting the shunting-signal to stop (Sh0). This will directly be detected by the SAMU-LEC. But similar as with driver operated shunting, this works only in the influence area of the signal.

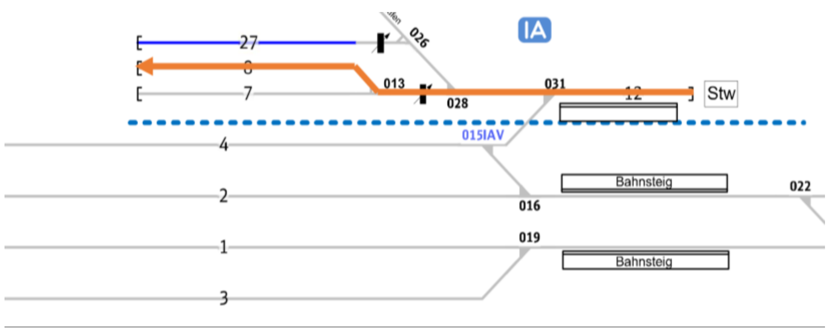

Figure 5: Infrastructure situation

2.5 Communication and localisation

Besides both interface units, a communication needs to be able to safely transfer the commands between infrastructure interface (SAMU-LEC) and vehicle (SAMU). Given the challenging conditions typically encountered in railway environment, an inductive or short range radio solution is preferable thanks to the expected safe communication at low latency.

It is foreseen to investigate a simplified inductive solution based on a trackside loop wire, marking the autonomous shunting area, similar to the physical layer of German LZB system. This wire may operate somewhere in a frequency range of 30-60 kHz. An other alternative may be dedicated short range radio communication (DSRC) and cellular communication via 5G network. Both the DSRC standard, which is a variant of WiFi communication utilised for Vehicle-to-Everything (V2X) communication and the cellular counterpart for V2X-communication (C-V2X) are interesting since the do not require significant investments. But all these alternative solutions have the big disadvantage of inaccurate localisation, especially concerning position of fouling point indicators in the switch area of the station. However the cost driver may be the homologation procedure, so a simple yet effective solution may be an inductive loop, requiring more installation effort, but offering a safe deenergise-to-apply solution to issuing and withdrawal of movement authorities. An inductive wire based solution may also enable the accurate localisation of fouling points and track locks. For other solutions, either Bluetooth Low Energy beacons or a high precision GNSS operated by a third party (US, Russian or Chinese Ministry of Defence or European Space Agency) are required. All this systems are beyond control of the railway operator and do only work properly, if free sight on at least 4 satellites is possible. This cannot be granted in (urban) railway environments, where bridges, buildings and platform roofs generate shadows.

2.6 Monitoring interface

In order to assess the status of the SAMU system and its elements, a web based monitoring interface is provided. This can be displayed on a fixed monitor or on a handheld device (e. g. tablet) and allows the staff to view error and status messages (e. g. pictures of obstacles on the track, battery status, speeds, etc.) and allows non safety critical interactions as defining the final stabling point or powering up/booting the EMU. This interface may be accessed via intranet or vpn. In case of need for safety critical functions (e. g. emergency stop push buttons on the platform or vehicle) these will need to be hard-wired to SAMU or SAMU-LEC.

3 Demonstration scenario

In order to demonstrate the feasibility of the concept, a demonstration run on public railway infrastructure is planned, moving a vehicle from its final operation platform to the stabling position as depicted in orange lines in Figure 5. The vehicle will be one of the SWEG fleet, also the infrastructure is owned an operated by SWEG.

The data collected in this scenario will be published in the form of ROS-Bags to an extent as large as possible. Also parts of the software will be made available.

4 Conclusion and perspective

This paper presents a project aimed at providing a simple yet effective automation solution for stabling of multiple units. The system is rooted in the SAMIRA project, where a cost effective driver assistance system was developed.

The next steps will be primarily the investigation for suitable interfaces, which form a major project basis and at the same time a risk.

Acknowledgment

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