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Design and Evaluation Examples of a Data Acquisition System for Light Rail Applications

Philip Otto[1], Markus Tesar[1], Peter Gratzfeld[1]

[1]Karlsruhe Institute of Technology (KIT), Institute of Vehicle System Technology, Rintheimer Querallee 2, 76131 Karlsruhe, Philip.Otto@kit.edu, Markus.Tesar@kit.edu, Peter.Gratzfeld@kit.edu

Summary

This publication gives an overview of the design and setup of a measurement system for carrying out comprehensive long-term measurements in the Karlsruhe tram network and presents a methodical procedure for equipping inventory vehicles of operators. In addition to the hardware equipment, solutions for the efficient storage and analysis of the data are also presented. The measurements from the operation show a manifold optimization potential regarding the energy efficiency of the overall vehicle and the DC tram network. Based on the measurement data, multi-physics simulation models can be validated and machine learning models can be trained. Thus, the project provides the basis for large-scale data studies that have come to the fore in the field of rail vehicles in recent years.

Keywords: Data Acquisition, Digitalization, Infrastructure, Maintenance, Public Transport

1 Introduction

In order to make public transport attractive and economical, it is important to have a comprehensive knowledge of the system and the interaction between its subsystems. This knowledge can be continuously expanded by measurements during regular passenger operations. In a cooperation project between the Albtal-Verkehrs-Gesellschaft mbH (AVG) and the Institute of Vehicle System Technology of the Karlsruhe Institute of Technology (KIT), a tram was therefore equipped with a modular, passive measuring system. The focus is on gaining new information about the vehicle, operation and infrastructure from the data. The extraction of knowledge from data is bundled in the new research field Data Science

This discipline derives from the interaction of computer science and information technology, statistical methods of mathematics and the expertise of the respective application area. With regard to the Karlsruhe Measuring Tram, current methods from IT for the analysis of large data sets in combination with procedures for machine learning from statistics are to be combined with the overall system competence of the railway system at the Institute of Railway System Technology as well as the decades of experience in the operation and maintenance of rail vehicles of AVG.

The optimisation of the railway system on the basis of a comprehensive database is also being investigated within the framework of other research projects. The measuring tram in Dresden is a cooperation project between the TU Dresden, Bombardier Transportation and the Dresden Transportation Services. The aim is to record the long-term wear and tear of the vehicle and infrastructure, energy efficiency and traffic flow, as well as acting accelerations and other mechanical measurement variables during regular passenger operation. [5]

EcoTram in Vienna is a research project initiated by the Vienna University of Technology, Siemens Mobility GmbH, SCHIG mbH, Rail Tec Arsenal and Vossloh Kiepe to increase the energy efficiency of air conditioning systems in tram vehicles. In this project, both the energy requirements of the auxiliary units and the external conditions during daily operation were recorded. [17]

The autonomous tram in Potsdam is a project of Siemens Mobility GmbH in cooperation with the Potsdam public transport company. In the project a tram was equipped with cameras for intelligent object recognition as well as lidar sensors for three-dimensional environment detection. The aim is to develop the first autonomous driving functions and test them in depot applications. [7]

The Department of Automotive Engineering at the Technical University of Darmstadt is researching together with HEAG mobilo GmbH on a "Feasibility Study on Automation and Assistance Systems for Trams" (MAAS Darmstadt). In this project, the potential of tram automation is to be demonstrated, driver assistance systems developed and the use of 5G technology for tele-operation tested. [20]

Deutsche Bahn's advanced TrainLab is also testing driver assistance systems, automated rail operations, new vehicle components, sensor systems and new radio technologies. [12] Together with DB Systemtechnik and SBB, Schweizerische Südostbahn is testing the use of acceleration sensors in the vehicle to monitor the condition of the infrastructure in order to reduce maintenance costs. [4] These projects show that, with the progress of digitisation, large-scale data studies have also entered the rail vehicle industry in recent years. A major focus in practical application is currently on the use of methods for the implementation of Condition-Based and Predictive-Maintenance systems. [6] This is expected to lead to a more efficient system on the one hand, and a better understanding of the vehicles by the manufacturers of the rail vehicles due to the large amount of recorded data on the other hand. Research activities include the remaining life time of vehicles, the condition monitoring of individual components in the vehicle and the condition monitoring of the rail infrastructure. [11, 16, 21]

In additional to improvements in maintenance, the aim is also to optimise daily operations. There is a wide range of research work on the prediction of delays and the prediction of passenger volume. [3,10,13,18]

2 System Design

The inner-city Karlsruhe tram network covers 71.5 kilometres. The system is designed for standard gauge vehicles and has a rated voltage of 750 V DC. The trams operate in the city area on routes that require BOStrab approval and operate beyond the city limits on AVG's owned EBO lines, so the vehicles must have both approvals. Over the whole year, the mileage of all vehicles is 17.4 million km and 166 million passengers are transported. [9] The measuring tram is used throughout the entire DC railway network.

The vehicle is the CITYLINK (NET2012) from Stadler [15]. The vehicle parameters are summarized in table 1.

Table 1: Vehicle parameter of the Stadler CITYLINK [15]

Parameter	**Value**
Vehicle Length	37.200 mm
Low-floor percentage	Approx. 80 %
Tare weight	Approx. 57,5 t
Propulsion	4 x 125 kW
Max. speed	80 km/h
Number of doors	5 passenger doors
Seats / Standing places	107 / 137
Catenary voltage	DC 750 V
Axle arrangement	Bo'2'2'Bo'
Approval	BOStrab / EBO

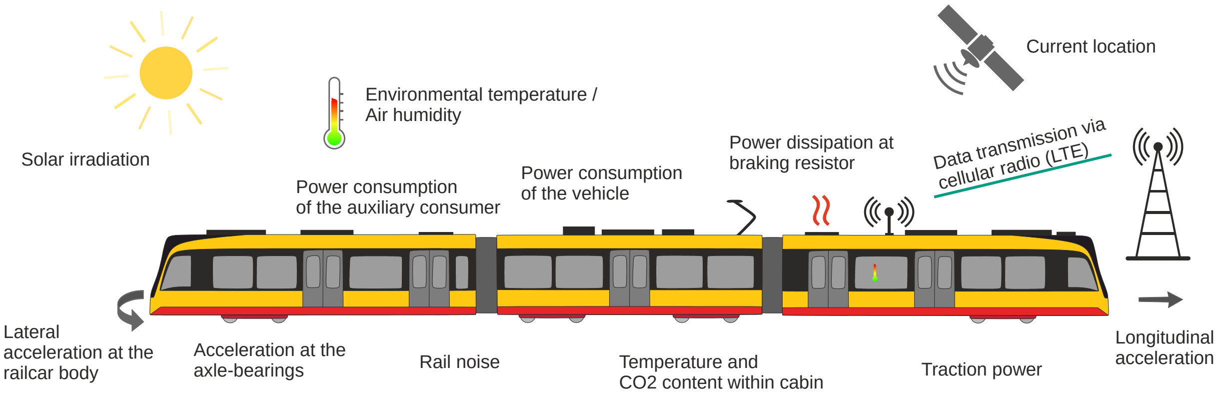

Figure 1: Recorded parameters of the measuring tram

In total, more than 150 measured variables are recorded. Figure 1 gives an overview of the recorded parameters. The channels can be divided into 5 groups: environmental parameters, passenger comfort, infrastructure, electrical parameters and further parameters. Table 2 lists a summary of the parameter groups and exemplary measured variables.

Table 2: Summary of the recorded parameters and its research objectives

Group	**Example Parameters**	**Research Objectives**
Environmental Parameters	Solar irradiaition Environmental temperature Air humidity Current location	Auxiliary consumer efficiency Enhancing passenger comfort
Passenger Comfort	Acceleration at the railcar body (longitudinal and lateral) Cabin CO2 content Cabin Temperature	Auxiliary consumer efficiency Increasing passenger comfort
Infrastructure	Acceleration at the axle-bearings Rail noise	Condition monitoring Noise reduction
Electrical Parameters	Power consumption of the vehicle Power dissipation at the brake resistor Power consumption of the auxiliary consumers Traction power	Energy efficiency Energy storage concepts
Further Parameters	Door opening duration Current Route Status Parameters	Driver assistance systems Vehicle localization Energy efficiency Condition based maintanance

The measuring points are distributed over the entire vehicle. The schematic system structure with the key components and their installation location is shown in Figure 2. In order to minimise interference in the signal lines, a modular measuring system was chosen due to the vehicle length of 37.2 m.An additional box was installed on the vehicle roof, in which the components for data transmission are integrated. Measurement cards for the sensors in the area of the bogies were installed in the driver's cab at the front and rear of the vehicle.

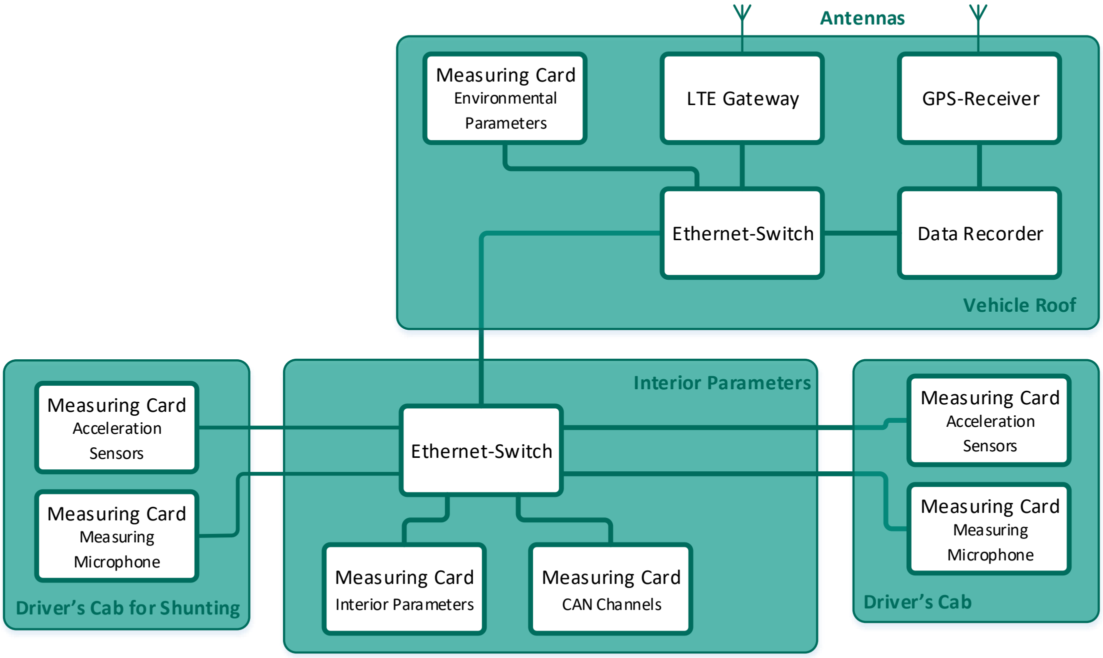

Figure 2: Schematic system structure

The system is supplied via the vehicle's internal 24 V on-board power supply system. An uninterruptible power supply (UPS) was integrated into the system to bridge short-term interruptions in the power supply.

The synchronization of the measurement cards with Ethernet is done via the Precision Time Protocol [5]. For the implementation it is necessary that the required Ethernet switches support this protocol.

The measuring system provides three freely selectable sampling rates. 48 kHz are used for the measuring microphones, the accelerometers are set to 2.4 kHz while the remaining parameters have a sampling rate of 10 Hz. The data recorder used allows downsampling during data acquisition. The high sampling rate of the measuring microphones results in large amounts of data, which is why a reduction of the measurement data is absolutely necessary. For this reason, trigger levels are set for the measuring microphones, above which the audio data is stored. In addition, the data is losslessly compressed and the recording is paused during the time it is in the depot.

Data is framewise transmitted via the mobile radio network with an LTE gateway (2x2-MIMO, uplink max. 50 Mbps possible). Each frame consists of measurement data with a length of 1 minute. If the mobile network is not available, data of up to 8 weeks can be buffered on the data recorder and no losses of data occur. The data is stored on a database server. PostgreSQL [14] with the extension TimescaleDB [18] is used as database. TimescaleDB increases the query performance of the database, since in general the evaluations are carried out via one or a small number of columns of the tables. To speed up large-scale analyses, an Apache Spark cluster was set up [2].

3 Evaluation Examples

As described in the previous sections, there are various aspects to evaluate the data. Some examples are shown below.

The amount of unused braking energy depends on many different parameters. With the measurements, the actual conditions in the tram network can be investigated and positions in the network can be found where a high proportion of unused braking energy is present. Figure 3 shows the power loss at the braking resistors. The section of line shown is located outside the city of Karlsruhe on the edge of the Black Forest.

Due to the high vehicle speed, the difference in altitude and the low cycle rate, a lot of braking energy is lost in the braking resistors in this section of the track. With this type of maps, investigations can be done to choose between mobile and stationary energy storage systems and which locations might be suitable.

Figure 3: Power dissipation at the braking resistor along the track

Auxiliaries are responsible for a high proportion of daily energy consumption. Figure 4 (left) shows the ratio of the energy demand of the auxiliary consumers in relation to the traction as a function of the average outside temperature. The graph on the right shows the amount of traction energy and auxiliary consumer energy as a proportion of total energy requirements. Approximately 32% of the total energy is consumed by auxiliary consumers. Taking into account, for example, door opening times and solar radiation, the measurement results can be used to create simulation models and implement optimization strategies.

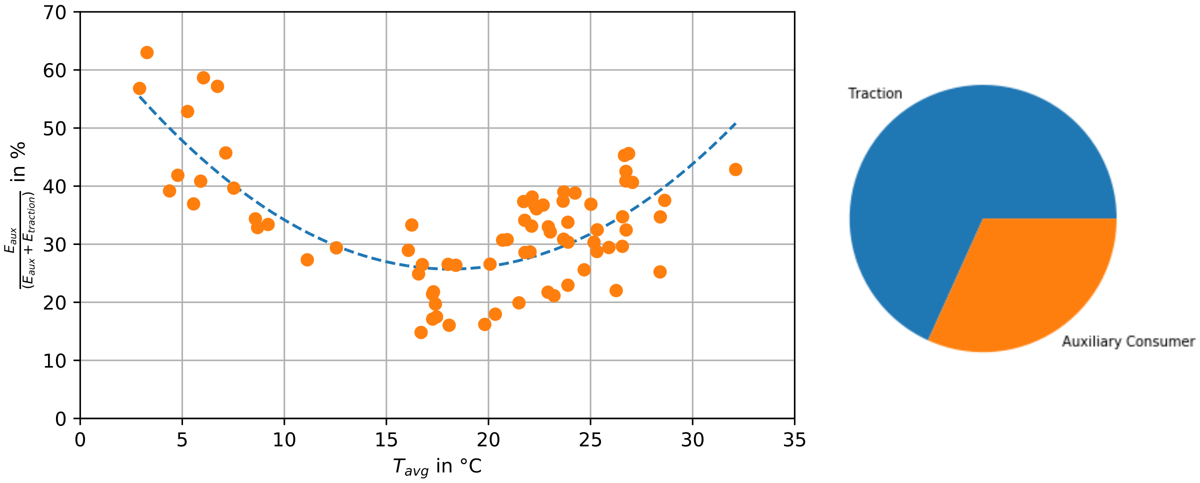

Figure 4: Ratio of auxiliary and total energy demand for various temperatures (left), ratio of traction energy and auxiliary consumer energy (right)

Figure 5 shows the measured accelerations at the traction bogie and the Fourier transform of the acceleration signals. Maintenance measures were carried out on the section of line being used and a new rail crossing was installed. The effects of these measures are clearly visible in the section of 10 to 40 seconds. The measured accelerations at the traction bogie are considerably lower in the range of 10 to 30 seconds due to the new track. This is also reflected in the frequency range. The newly installed rail crossing is also clearly visible at 30 seconds. Through interaction with the crossing infrastructure, very high accelerations of up to 25 g are measured, which are also clearly visible in the frequency spectrum.

These evaluations show that it is possible to monitor the condition of trail infrastructure using the acceleration sensors at the traction bogies. Measurements over longer periods of time can also be used to establish a degeneration model for the infrastructure.

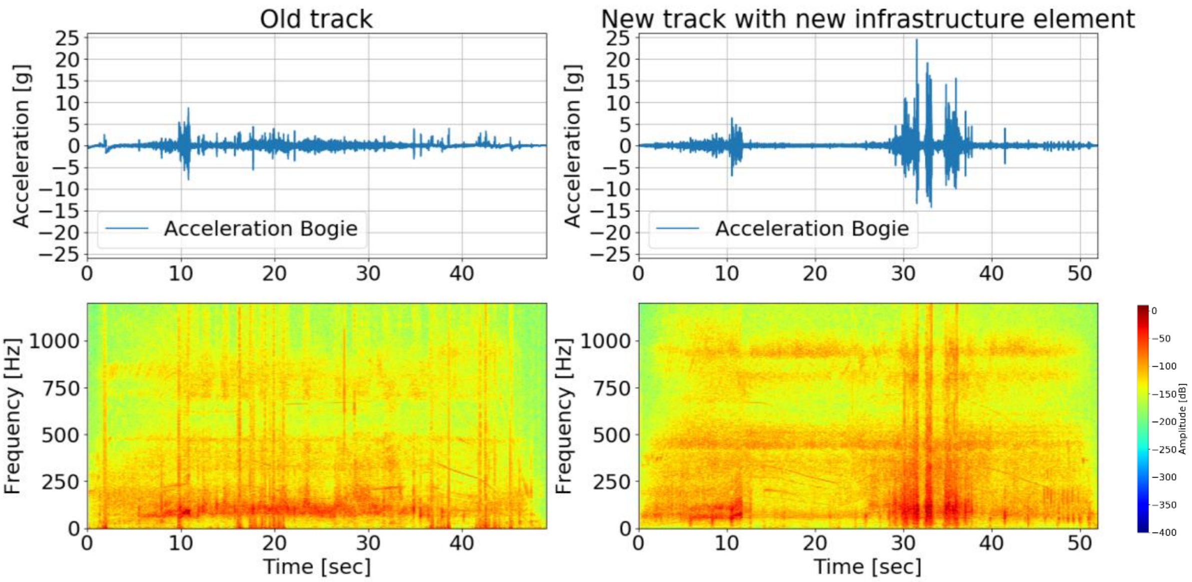

Figure 5: Acceleration at bogies and Short-time Fourier transform

4 Conclusion and Outlook

The Karlsruhe measuring tram is part of a multitude of digitization projects in the rail vehicle sector. The comprehensive and modular approach distinguishes the system from previous projects. Additional extensions to the system are very well possible due to the design, so that in future integration of further sensor technology such as cameras, lidar or radar sensors for testing autonomous driving functions is conceivable.

Analyses of the measured data show that first valuable insights into effects of acceleration, energy required for air conditioning and losses at the braking resistor have already been gained. In the future, methods from the field of machine learning will be used to extract even more knowledge from the existing data. This can be used in a goal-oriented and beneficial way to increase energy efficiency, capacity and punctuality and thus also customer satisfaction, which ultimately benefits operators, manufacturers and passengers alike.

References

[1] Albtal-Verkehrs-Gesellschaft mbH, NET 2012; https://www.avg.info/geschaeftskunden/fahrzeuge/net-2012.html (last accessed on 18.03.2020)

[2] Apache Spark, Lightning-fast unified analytics engine; https://spark.apache.org/ (last accessed on 18.03.2020)

[3] Berger, A. et al., „Stochastic Delay Prediction in Large Train Networks, "ATMOS 2011 – 11th Workshop on Algorithmic Approaches for Transportation Modeling, Optimization and Systems" (2011)

[4] DB Systemtechnik, Schweizerische Südostbahn mit Onboard-Monitoring für die Infrastruktur; https://www.db-systemtechnik.de/dbst-de/news/meldungen/meldung_schweizer-suedostbahn_onboard-monitoring-3442416 (last accessed on 18.03.2020)

[5] Dürrschmidt, G., Beitelschmidt, M., Harter, M., 5 Jahre Messstraßenbahn Dresden – Erfahrungen und Auswerteprojekte; in ETR 06/2014, S.36-41; Hamburg, Juni 2014

[6] Ghofrani, F., He, Q., Goverde, R.M.P. et al., Recent applications of big data analytics in railway transportation systems: A survey, Transportation Research, Part C 90, pp. 226-246 (2018)

[7] Hofmann, M., Last, H., Klier, C., Die erste autonome Tram von Siemens – Erfahrungen und Herausforderungen aus dem Forschungsprojekt mit den Verkehrsbetrieben in Potsdam ViP; 45. Schienenfahrzeugtagung Graz, Vortrag; Graz, April 2019

[8] IEEE 1588-2008 - IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems (2008)

[9] Karlsruher Verkehrsverbund, Strukturdaten https://www.kvv.de/unternehmen/zahlen-fakten/strukturdaten.html (last accessed on 18.03.2020)

[10] Kecman, P. and Goverde, R.M.P., Online Data-Driven Adaptive Prediction of Train Event Times, IEEE Transactions on Intelligent Transportation Systems, pp. 465-474 https://doi.org/10.1109/TITS.2014.2347136 (2015)

[11] Li, Z and He, Q., Prediction of Railcar Remaining Useful Life by Multiple Data Source Fusion, IEEE Transactions on Intelligent Transportation Systems https://doi.org/10.1109/TITS.2015.2400424 (2015)

[12] Müller, C., Digitalisierung im Test: Versuchszug, Teststrecke und Forschungscampus; in ETR 01+02/2019, S. 63-65; Hamburg, Februar 2019

[13] Oneto et al., Train Delay Prediction Systems: A Big Data Analytics Perspective, Big Data Research, Volume 11, pp. 54-64 (2018)

[14] PostgreSQL, PostgreSQL: The World's Most Advanced Open Source Relational Database; https://www.postgresql.org/ (last accessed on 18.03.2020)

[15] Stadler, NIEDERFLUR-STADTBAHN CITYLINK Verkehrsbetriebe Karlsruhe GmbH (VBK) und Albtal-Verkehrs-Gesellschaft (AVG), Deutschland; https://www.stadlerrail.com/media/pdf/lrvbkavg0116d.pdf 2014 (last accessed on 18.03.2020)

[16] Struckl, W. M., Richter, G., Ecotram – Verbesserung der Energieeffizienz im Bereich der thermischen Komfortsysteme; in ETR Austria 09/2014, S. 156-160; Wien, September 2014

[17] Su, Z. et al., Model Predictive Control for rail condition-based maintenance: A multilevel approach, IEEE 19th International Conference on Intelligent Transportation Systems (ITSC), https://doi.org/10.1109/ITSC.2016.7795579 (2016)

[18] Sun et al, A novel wavelet-SVM short-time passenger flow prediction in Beijing subway system, Neurocomputing, Volume 166, pp. 109-121 (2015)

[19] TimeScaleDB, TimescaleDB: An open-source database built for analyzing time-series data with the power and convenience of SQL; https://www.timescale.com/ (last accessed on 18.03.2020)

[20] TU Darmstadt, Fachgebiet Fahrzeugtechnik, Machbarkeitsstudie zur Automatisierung und Assistenzsystemen der Straßenbahn; https://www.fzd.tu-darmstadt.de/forschung/research_projects_fzd/maas_fzd/index.de.jsp (last accessed on 18.03.2020)

[21] Vale et al, Novel Efficient Technologies in Europe for Axle Bearing Condition Monitoring – the MAXBE Project, Transportation Research Procedia, Volume 14, pp. 635-644 (2016)

Authors

	Dipl.-Ing. Philip Otto (35) studied electrical engineering at the TU Berlin and worked afterwards as a hardware and software developer for individual electronic components in the field of industrial and medical electronics. Since 2016, he has been a research assistant at the Institute of Vehicle System Technology at the Karlsruhe Institute of Technology (KIT) and is conducting research on efficient energy supply in DC local transport networks.
	Markus Tesar, M.Sc. (27) studied Eletrical Engineering and Information Technology at the Karlsruhe Institute of Technology. He wrote his master’s thesis on the Design Methodology for the Electrifcation of Urban Bus Lines with Battery Electric Buses. Since 2018 he has been working as a Research Associate at the Institute of Vehicle System Technology at the Karlsruhe Institute of Technology. There he is working on the project of the Karlsruhe Measurement Tram and is conducting research on the optimization of the energy efficiency of trams.
	Prof. Dr.-Ing. Peter Gratzfeld (64) studied Electrical Engineering and wrote his doctoral thesis at the Rhein-Westfälisch Technische Hochschule (RWTH) Aachen. He then held various management positions in engineering, project management and executive management in the railway sector at BBC, ABB, ABB Hentschel, Adtranz and Bombardier Transportation. Since 2008 he holds the professorship for Rail System Technology and is head of the Institute of Vehicle System Technology at the Karlsruhe Institute of Technology (KIT).