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MENDEL: Minimum load of electrical networks caused by charging operations of electric buses

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Summary

The German MENDEL research project aims to minimize the total operating costs of electrically powered bus fleets. This includes a cost reduction for the construction and operation of charging infrastructures for electric buses by minimizing the load on the power grid by optimizing the charging process in space and time, as well as reducing the energy consumption of the vehicles in operation. The project combines the two fields of smart grid and intelligent traffic systems to a prototypical system concept in the German city of Brunswick which should be subsequently transferable to other cities.

Keywords: research, public transport, telematics, smart grid, power management

1 Introduction and Goals

State-of-the-art electric driven buses used by local public transport authorities are usually restricted in their daily driving distance caused by limitations in their battery capacity. To compensate for these limitations especially on longer urban bus lines the vehicles need to be recharged with a high energy performance on short intermediate stops. In the future when entire bus fleets will be operated only electrically, a lot of buses have to be charged at the same time which will result in peaks of high energy consumption within the grid and increasing costs at the same time [1].

The project MENDEL (minimum load of electrical networks caused by charging operations of electric buses) is funded by the German Federal Ministry of Economics and Energy to address the problem mentioned in [1]. The project duration is three years, beginning from 2016 until the end of 2018. Six German partners and three associates coming from different research areas and the industry (see the list bellows) are involved with the MENDEL project and are working together to achieve the project objectives.

The specific MENDEL step by step objectives are:

- Planning tool for charting infrastructure
- Optimal load and operation management
- Tool for public transport timetable planning

- Extension of the ITCS Center (intermodal transport control system)
- Extension of the ITCS On-board Unit
- Building a simulation environment
- Building an information and communication platform
- Traffic lights communication paths in the cooperative system
- Control methods in the cooperative system
- Hybrid switching time forecast by the Smart Traffic Center (STC)
- Prioritization of public transport by the STC
- public transport driver assistant system

MENDEL Partners:

- AVT STOYE (German signal control and traffic technology manufacturer)
- Fraunhofer IML (Research Institute for Material Flow and Logistics)
- INIT (German/worldwide ITS solutions in public transportation)
- ifak (Research on Information and Communication Technology and Automation)
- GEVAS Software (Solutions in the area of traffic technology)
- German Aerospace Center (DLR), Institute of Transportation Systems

Associated MENDEL Partners:

- BS Netz (German electric grid operator in the city of Brunswick)
- Braunschweiger Verkehrs-GmbH (Local public transport authority in the city of Brunswick)
- BELLIS (Traffic service provider in the city of Brunswick)

The goal of MENDEL project is to support the introduction of electric driven buses into existing fleets of public transport authorities and the intelligent fleet management in order to stimulate the complete replacement of conventional gasoline-fuelled buses by electric buses as in [2]. The generic and modular IT system developed in MENDEL project provides standardized interfaces for different purposes. The system is currently customized to be operated for the German city of Brunswick and should be subsequently transfer to other cities.

The key innovation of the MENDEL prototypical system is the combination the two domains Smart Grid and Intelligent Transportation Systems (ITS) through automation (see [3] and [4]).

The short description of the two terms is provided as follows:

- Smart Grid:
  This term covers the communicative networking and control of electricity generators, storage units, electrical consumers and network equipment in energy transmission and distribution networks of the electricity supply. The aim is to ensure energy supply on the basis of an efficient and reliable system operation. In particular, the communicative networking of network resources and vehicles as electrical consumers strikes the bridge to the intelligent traffic systems.
- Intelligent transportation systems
  aim to provide innovative services in various transport sectors and traffic management, and to provide the various users with more comprehensive information and enable them to provide the transport networks with safer, more coordinated and "clever" services (see [5]). The use of information and communication technology will contribute to energy efficiency.

2 Hierarchical Structure of Automation Tasks

The MENDEL project uses the automation task approach to achieve the project requirements. This section presents a short overview about the hierarchical structure of automation tasks.. The automation tasks can be represented hierarchically in a layered model as described in [6]. Each layer contains several interactions that consist of sub functions which cooperate with their superordinate or subordinate layers in the sense of requirement boundary conditions. The automation tasks consist of three levels as described bellows::

- Strategic level:
  At this level an optimization of loading infrastructure and vehicle deployment takes place. When planning the vehicle circuits and the services, the necessary charging processes are already taken into account in such a way that the charging requirements of all buses are minimal at all times.

- Tactical level:
  At this level, load management is optimized during operation. Intelligent services regulate the total charging capacity in the medium voltage network, knowing (a) the current operating state, (b) actual charging conditions of the buses, (c) forecasting energy requirements, and (d) the maximum power supply at the charging points. This is done, for example, by operating driving instructions (e.g. extended periods of stay at the loading point).

- Operational level:
  At this level, an energetic optimization of the driving strategy takes place. In order to avoid frequent stops, particularly in urban traffic, followed by energy-intensive start-up operations on light signal systems, a cooperative driver assistance function is created. This function combines vehicle and infrastructure functions.

The above-described abstract automation tasks are implemented in automation functions. The next section presents the MENDEL system concept und gives some information about the system realization and the guideline.

3 MENDEL System Concept

Various possibilities exist for the realization of automation tasks or functions described above. All these automation tasks depend on the technical equipment or devices of the traffic carriers. Figure 1 depicts the MENDEL cooperative system architecture as designed and prototypical realized within the MENDEL project. It consists of field level, cooperative traffic and load management level and planning level. The project MENDEL is characterized by an integrative approach, which links the two domains of Intelligent Transport Systems (ITS) and Smart Grid . Therefore the resulting potentials are lifted with a holistic optimization of these aspects, which have so far been considered separately.

The MENDEL project uses online algorithms for an optimized load management in the operation of electrically powered bus fleets. These algorithms include the identification of usage conflicts during operation (e.g. workload of the charging points), as well as providing adequate conflict resolution approaches [7].

On the other hand, the project MENDEL designs an architecture concept of a cooperative system which connects the local traffic signal control system, the traffic management centre as well as the intermodal transport control system (ITCS) of the public transport authorities. Necessary extensions in the communication chains between vehicles and transport infrastructure are carried out on the basis of manufacturer-independent standards (OCIT and VDV see [8] and [9]). Control procedures and communication paths in the cooperative system network are expanded with regard to relevant guidelines for the control units (VDE see [10]) and for traffic signal planning (RiLSA see [11]). In addition, services for the energy-efficient driving of electrically driven buses are implemented prototypically. This includes both infrastructure aspects (e.g., hybrid green light prognosis) as well as aspects on the vehicle side (e.g., calculation of an energy-optimal vehicle trajectory).

In the so-called Smart Traffic Center (STC) information from the traffic light controllers are merged with the control technologies of the public transport system to form the link between the electric grid and the traffic management system. These information are evaluated in real-time and can be forwarded to the bus driver through intelligent assistance systems in the vehicle. With the information from the Smart Traffic Center, for example, the precise position and the current charging state of the electric bus can be recorded and evaluated instantly. This allows the bus driver to get information like when and where to recharge for the next time and how long this process will take. The red phases of the traffic light systems will also be predicted with the new system which will be able to provide a speed recommendation for an energy-efficient ride to the bus via the assistance system. In addition, the bus can also communicate with the traffic light system, send its position, and wait for pre-emption from the Smart Traffic Center, which allows passing the traffic light without any stop.

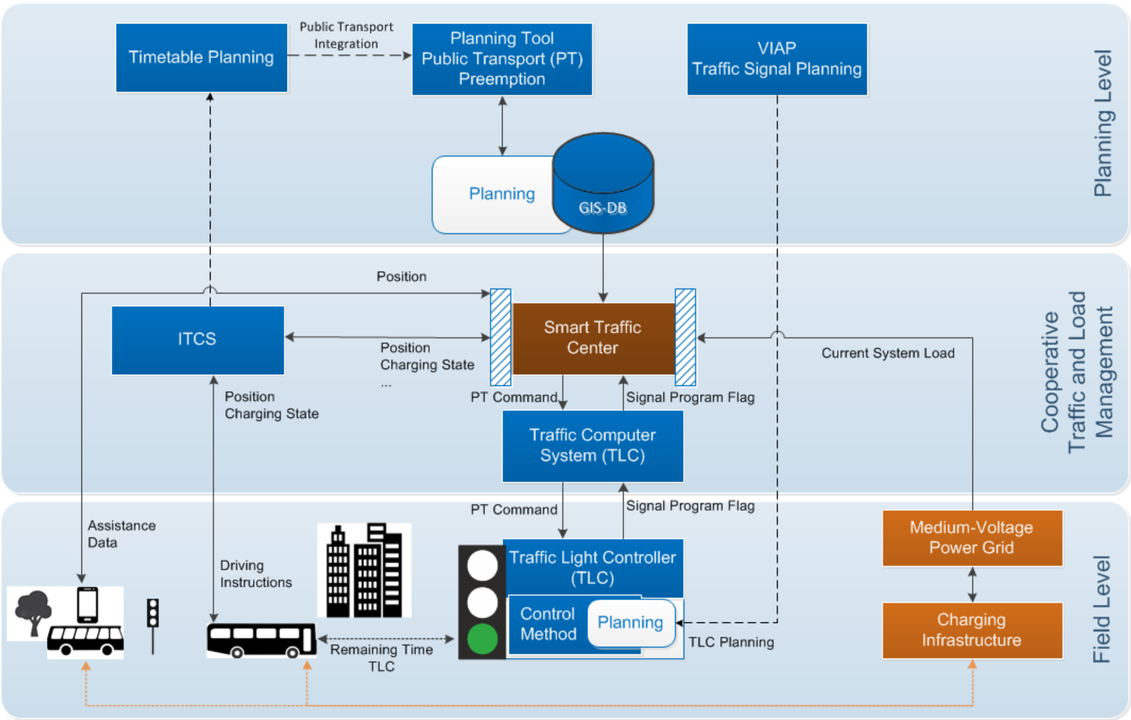

Figure1: Cooperative MEDNEL system of ITS components
(traffic light system, intermodal transport control system) and smart grid

4 Testing of the MENDEL Concept

To demonstrate the feasibility of the ITS concept developed in the MENDEL project three different tests (in simulation, in laboratory and in the field) have been conducted in virtual environment as well as in real world operation. The aim of test is to evaluate for example the reliability, robustness and the actuality of the system. In the following section is described the three tests in details.

4.1 Testing in the Simulation

Within the the scope of the MENDEL project two, simulations using different simulation tool suite are performed. For both simulations, different field-specific simulation suites are used which are going to be linked to gain the required outputs. The ifak (Institut für Automation und Kommunikation) is responsible for the simulation of the electricity network in the project and this simulation is not described in detail here. Traffic flow simulation is performed by the DLR using SUMO (Simulation of Urban Mobility) [12].

SUMO is a free and open traffic simulation suite which is available since 2001 and developed by DLR. SUMO allows modelling of intermodal traffic systems including road vehicles, public transport and pedestrians. SUMO also offers is a wealth of supporting tools which handle tasks such as route finding, visualization, network import and emission calculation. SUMO can be enhanced with custom models and provides various APIs to remotely control the simulation. The simulation platform SUMO offers a lot of specific features:

- Microscopic simulation - vehicles, pedestrians and public transport are modelled explicitly

- Online interaction – control the simulation with Traffic Control Interface (TraCI)
- Simulation of multimodal traffic, e.g., vehicles, public transport and pedestrians
- Time schedules of traffic lights can be imported or generated automatically by SUMO
- No artificial limitations in network size and number of simulated vehicles
- Supported import formats: OpenStreetMap, VISUM, VISSIM, HERE
- SUMO is implemented in C++ and uses only portable libraries

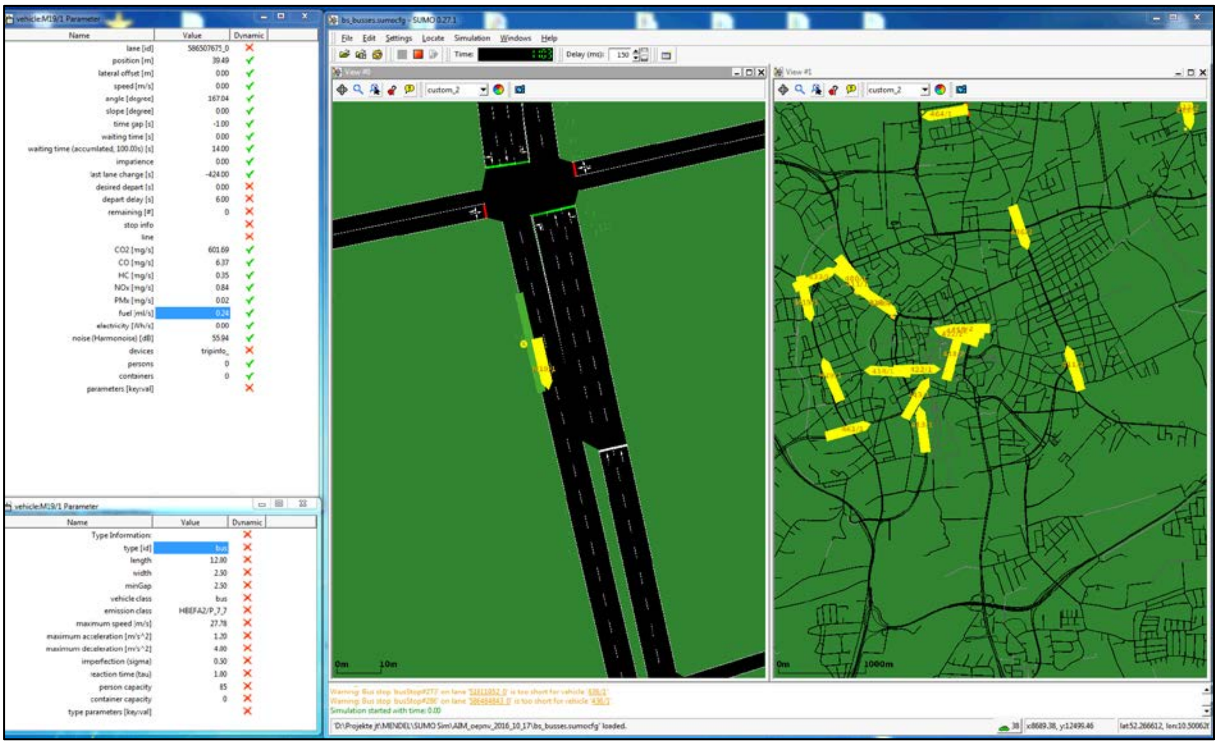

Figure2: Visualization and key figures of a bus in the traffic flow simulation platform SUMO

SUMO is used in the project MENDEL to test various individual components of the overall system concept. For this purpose, the road network of the city of Brunswick, as well as the existing bus lines and the traffic demand were simulated. Furthermore all necessary bus stops, traffic lights and charging stations were added (see Figure 2). System components such as simulated energy consumption and inductive recharge at bus stops, bus pre-emption at traffic lights and the interaction with individual traffic are tested in different scenarios. The simulation results are compared with each other and are benchmarked with the forecasted, desired behaviour of operation. In addition, input for the simulation of the electricity network is generated by SUMO, based on the utilization of the charging stations. Conversely, usable charging capacities and favourable charging periods are provided by the simulation of the electricity network to SUMO.

The simulations of the traffic flow and the electricity network are now performed. Results are available soon; they will be published in articles and on the website.

4.2 Testing in the traffic signal laboratory (DLR LSA-Lab) and the DLR test site

Software components can be tested well using simulations. However, technical solutions and new hardware components should not be immediately tested in the real traffic field where they can fail and cause traffic jams or worse.

The LSA-Lab (traffic signal control and engineering) [13] therefore acts as a link between computer supported simulation and field testing under real conditions for new technology in the field of traffic signal control. The LSA-Lab in the DLR is a development and test environment for traffic signal control equipment. It enables the testing of new sensor technology components, the implementation of new hardware interfaces, the testing of innovative control processes, the check of traffic signal control modifications for passing into the field as well as the networking with other traffic signal control devices. The laboratory is equipped just like real junctions with additional hardware and software components (see Figure 3). Tests and demonstrations can be carried out in the laboratory itself or in a closed-off outdoor area.

Figure3: LSA-Lab - traffic signal control and engineering in the German Aerospace Center (DLR)

The LSA-Lab and the DLR test site are used in MEDNEL to test new functions of communication between vehicles and infrastructure. Here, new information about the state of charge, public transport data and traffic light data are transmitted. Furthermore, the vehicle-specific adaptations of the bus operating system are tested on the test ground. For the tests, various campaigns in the laboratory and the test site are carried out and evaluated in order to prepare the components for a field test.

4.3 Testing in the field

Field tests are a major part within MENDEL. In this way, a comprehensive assessment of the efficiency, quality and robustness of the intelligent communication technology solutions developed in the project for the energy-efficient driving of electric buses should be achieved. The field tests carried out in the MENDEL project represent a first step for the market introduction of mature system solutions, which have already demonstrated their fundamental effectiveness in the laboratory and in simulation studies. In DLR laboratories, at the DLR test site and the already existing test and research infrastructure in the city of Brunswick (see section 4.3.2), as well as the electrically driven bus fleet already tested during operation (see section 4.3.1), are ideal prerequisites for field testing.

4.3.1 Implementation of the electrically powered bus fleet in the MENDEL project

The electrically driven buses used by Brunswick public transport authority are charged with the PRIMOVE charging system developed by Bombardier [14]. As part of the emil project [15], five charging stations have been installed, three of them have already been in operation since the end of 2013. Two loading points at the end stop secure the maintenance charge. Two additional charging stations are installed at bus stops where the vehicles commonly stop longer. A further charging station is located in the bus depot where the vehicles are charged and prepared for the operation on the next day. In the emil project, four buses (a 12m bus (see Figure 4) and three single-articulated buses) were tested in regular operation. The 12m bus has been in continuous operation since early 2014. In the follow-up project InduktivLaden [16] a complete electrification of the bus line M19 was implemented. The inductive energy transmission of the charging system PRIMOVE can be integrated into the line operation without any disabilities for passengers and without any effort for the driver since no charging cables have to be handled. The energy transmission is automatically initiated by the correct positioning of the vehicles via the charging stations. The energy transfer with a charging capacity of more than 200 kW and with efficiencies of more than 90% corresponds to more than three times the charging power, which is maximally available in the case of charging systems for electric cars in series solutions (compare [17] and [18]).

Figure4: Solaris Urbino 12m bus with Bomardier PRIMOVE charging technology

4.3.2 Integration of the MENDEL system into the Application Platform for Intelligent Mobility

With the Application Platform for Intelligent Mobility (AIM) [19], a comprehensive kit for the development and prototypical testing of intelligent mobility services is available at the Institute for Transportation Systems of the German Aerospace Center (DLR) (see [20] and [21]). With the long-term operation of the research infrastructure up to the year 2028, DLR goes far beyond the scope of conventional research projects with temporarily operated plants. The research infrastructure created is available for joint projects with partners from industry and science. The reuse of existing building blocks leads to a cost and time saving in the practical demonstration of scientific knowledge. The reference track for vehicle-to-infrastructure communication (V2X) consists of a more than 12-km-long stretch with a total of 35 traffic lights equipped for the operation of cooperative driver assistance systems. The individual intersections are equipped for data transmission with the IEEE 802.11p (communication with motor vehicles) and IEEE 802.11 b/g/n (communication with non-motorized traffic) standards (see Figure 5).

Figure5: Transmitters and Receivers for vehicle-to-infrastructure communication (V2X)

5 Conclusion and Outlook

The MENDEL (minimum load of electrical networks caused by charging operations of electric buses) research project, which the aim is to minimize the total operating costs of electrically powered bus fleets and the intelligent management is presented in this paper. The current state of the implementation is also presented. The requirement analysis and interface specifications had been done for the complete system. The implementation of the necessary interfaces and software is started in 2017.

Within the scope of the MENDEL project, simulations of the traffic flow and the electricity network are now performed. For both simulations, different field-specific simulation suites are used which are going to be linked to gain the required outputs. For the implementation of the technical solutions, field tests and evaluations are planned in the AIM test field in the German city of Brunswick. With its Application Platform for Intelligent Mobility (AIM), the German Aerospace Center (DLR) has created a research infrastructure for future intelligent transportation and mobility services which will also be used in MENDEL.

The results are to be integrated and evaluated in the field study and can be used in the city traffic management center of Brunswick. The standardization e.g. in the OCIT Development Group (Open Communication Interface for Road Traffic Control Systems) and in the Association of German Transport Companies (VDV) together with practical tests ensures the future transferability of the approaches developed in the MENDEL project to other cities.

The project ends in December 2018. There is still a lot to do and to test. Once the initial results are available, they will be published in articles and on the website.

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Robert Oertel finished his studies in Transport and Transportation Engineering at Dresden University of Technology, Germany, in 2009. Afterwords he has been with German Aerospace Center (DLR), Institute of Transportation Systems and finished his PhD there in 2014, dealing with the topic of “Delay-based Traffic Signal Control”. Currently he is working as a DLR project manager and engineer focused on the research fields of traffic management, traffic simulations and traffic signal control.