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Insights into the Operation of Overhead Line Hybrid Trucks on the ELISA Test Track

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Summary

The awareness for fuel usage of heavy-duty vehicles and its consequences for environment and transport costs are getting into focus of stakeholders. Therefore, the ELISA project has equipped a five kilometre section of the motorway A5 in the German Federal State of Hessen with the eHighway system in both directions. It's of particular interest to analyse the practical operation of "Overhead line Hybrid trucks" (OH truck) using a catenary system for electric energy supply. Based on results from dedicated research drives, different truck operation modes were identified, and a driver-vehicle-environment model was adapted to the specific conditions of OH trucks.

1 Research Questions

Regarding the overall traffic system, fuel usage of heavy-duty vehicles and the consequences for the environment receive increasing attention from different stakeholders, e.g. transport companies, society or affected government representatives. The eHighway system is one possibility to tackle this challenge by allowing trucks to be fed with electric energy from a catenary [1]. "An efficient implementation of such system requires studies in different fields to understand the impacts of the eHighway system on today's road infrastructure. For that purpose, the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety is funding three field trials, and the project ELISA (Elektrifizierter, innovativer Schwerverkehr auf Autobahnen) is the most advanced of them. In ELISA – a 5 kilometre section of the motorway A5 in the German Federal State of Hessen – is equipped with the eHighway system in both directions. The project is led by the respective road authority Hessen Mobil, and Technische Universität Darmstadt is responsible for the accompanying research" [1].

In cooperation with research partners, Technische Universität Darmstadt elaborated a comprehensive, diversified research concept. For instance, subject areas such as influences of the eHighway system on transport companies, catenary system operators or energy supply system operators are focused. Furthermore, questions related to energy demand and ecological impact of the eHighway system shall be investigated. As part of the research on the energy demand by "Overhead line Hybrid trucks" (OH trucks), this paper will focus on the following research questions:

- Which different operation modes of an OH truck exist?
- In what way can OH truck drivers influence the OH truck operation?

2 Methodology

Since Mai and September 2019, the first two OH trucks are in operation for two out of five transport companies partnered with ELISA. During the daily operation data from the OH trucks is collected. In addition, specific research drives with the same vehicles were conducted under monitored conditions to focus on selected questions relating to the OH truck operation modes. The dedicated research drives reported in this paper took place on a Wednesday in December 2019, following and adapting the "Empfehlungen für Verkehrserhebungen (EVE)" [2]. The used OH truck is based on a Scania R450 A4x2NB R17N – a tractor unit with trailer – equipped with a pantograph by Siemens. The OH truck is primarily determined by its parallel hybrid function using a combustion engine (450 hp), an electric engine (130 kW) and a battery unit (18 kWh)[1]. Data was collected using a data logger integrated into the OH truck and analysed by using the statistics software R [3].

Based on the findings on the operation modes, a driver-vehicle-environment model was considered to explain the differences in operation between a truck operated with only a combustion engine – referred to as a conventional truck – and an OH truck. The combined model by Donges and Rasmussen [4] as well as the model by Wimmer [5] were adapted to the OH truck operation by investigating driver behaviour and driver information during research drives.

3 Results

OH Truck Operation Modes

The OH truck operation modes are defined by the interaction of the combustion engine, the electric engine as well as the energy suppliers (fuel, recuperation, catenary system and battery). For an OH truck two basic modes are possible: hybrid and electric mode. These modes can further be divided into six sub-modes.

Hybrid sub-modes:

- **Hybrid – standard mode:** The energy for the drive is taken in a flexible way from the combustion engine and the electric engine. Energy for the electric engine is taken from the battery. The battery is fed by the diesel engine or by recuperation via the electric engine.
- **Hybrid – forced charging mode**: The combustion engine is forced to produce exceed energy to charge the battery.
- **Hybrid – catenary mode:** The energy for the drive is taken in a flexible way from the combustion engine and the electric engine. Energy for the electric engine can be taken from the catenary or from the battery. The battery is fed by the catenary, by the diesel engine or by recuperation via the electric engine.

Electric sub-modes:

- **Electric – standard mode:** The energy for the drive is taken form the electric engine. Energy for the electric engine is taken from the battery. The battery is fed by recuperation via the electric engine.
- **Electric – forced mode:** The OH truck is forced to use the electric engine for the drive. Energy for the electric engine is taken from the battery. The battery is fed by recuperation via the electric engine.
- **Electric – catenary mode:** The energy for the electric engine is taken from the catenary or from the battery. The battery is fed by the catenary or by recuperation via the electric engine.

In the current OH trucks, a diesel mode with traction by only a combustion engine cannot be observed. This is due to the system structure of the parallel hybrid. In this case the electric engine cannot be switched off. It is needed either to provide energy for the drive or to recuperate energy and feed it into the battery.

[1] In the course of ELISA, different generations of OH trucks will be operated having different equipment, e. g. regarding the electric engine. The OH truck described in this paper is defined as OH truck – Generation 1.

For this paper, research drives with an OH truck under monitored conditions were conducted to verify the theoretical OH truck operation modes. Therefore, two parameters from the collected vehicle data, the battery SOC and the fuel rate, were analysed. In this first analysis, four different OH truck operation sub-modes were observed (figure 1). This includes all mentioned hybrid modes. However, since the power of the electric engine (130 kW) is quite low, among the electric modes, only the electric forced mode was clearly observable with sufficient data, so far. Of course, further research will aim to observe and to verify the other sub modes, as well.

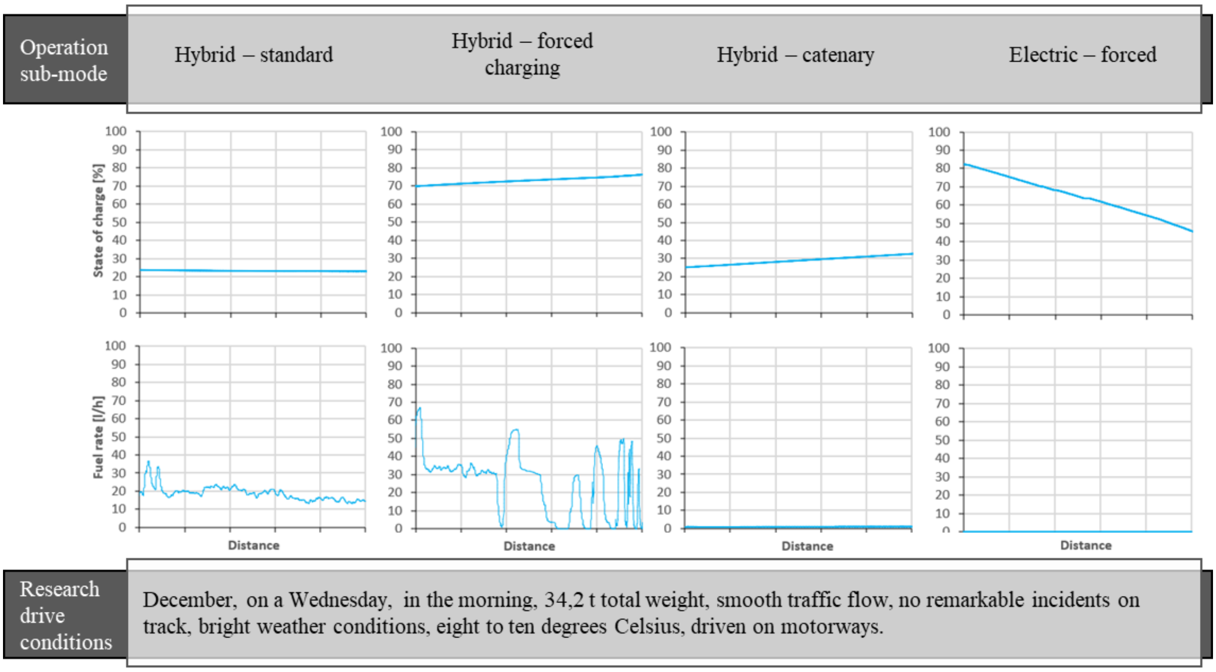

Figure 1: Illustration of battery state of charge and fuel rate depending on OH truck operation sub-mode[2].

The most significant findings from the four observed operation sub-modes are:

- Hybrid – standard mode: The observed fuel rate, which is lower than for a conventional truck, meets the expectations.
- Hybrid – forced charging mode: Compared to the operation in hybrid standard mode, in hybrid forced charging mode a higher fuel consumption can be observed. The main reason is the additional energy needed for charging the battery.
- Hybrid – catenary mode: A small fuel consumption under the catenary system can be observed.
- Electric – forced mode: A zero fuel consumption can be observed.

Driver-Vehicle Interactions

For the analysis of the interactions between the OH truck, the OH truck driver and the environment, driver behaviour models were considered. These models are based on the concept of the human-machine-system [4]. In this case, an information exchange takes place between the OH truck and its driver, starting with an order in form of a transport task from outside the system. The developed model is illustrated in figure 2.

[2] The graph is based on conducted research drives. The scaling for the distance is not declared because the values are based on single research drives, only. Any conclusions regarding fuel and electric energy consumption rates need further cross checking with daily OH truck operation data and further research drives.

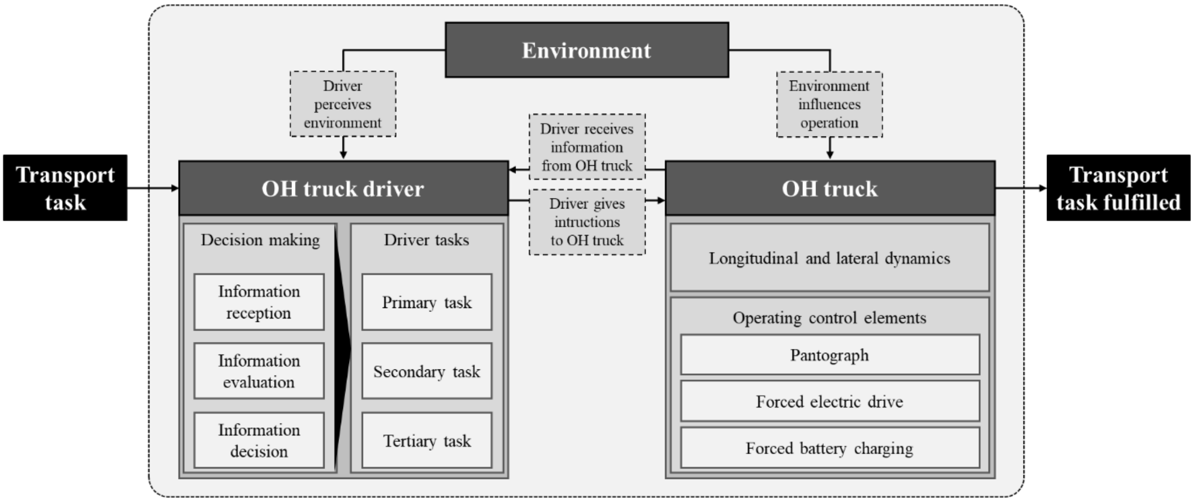

Figure 2: Driver-Truck-Environment model for an OH-Truck, following [3, 4]

The OH truck driver is one essential part of the driver-vehicle-environment model. His driving task can be differentiated into three categories. The primary tasks are characterised by the driver's responsibility for the longitudinal and lateral control of the vehicle. The secondary tasks are to manage support systems, e.g. Stop&Go, adjusting the headlights or using the turning signal. The tertiary tasks are not related to the main driving tasks and consider the driver's comfort [4]. Changing the operation mode of the OH truck can be regarded as a secondary task. Compared to a conventional truck driver, the OH truck driver has additional operating control elements in the cockpit to influence the truck operation sub-mode based on his perception of the environment and the current operation state of the OH truck (figure 3).

	Hybrid – standard mode	Hybrid – forced charging mode	Hybrid – catenary mode	Electric – forced mode
Operating control elements	Pantograph: **DOWN** Forced electric drive: **OFF** Forced battery charging: **OFF**	Pantograph: **DOWN** Forced electric drive: **OFF** Forced battery charging: **ON**	Pantograph: **UP** Forced electric drive: **OFF** Forced battery charging: **OFF**	Pantograph: **DOWN** Forced electric drive: **ON** Forced battery charging: **OFF**

Figure 3: Operating control element status depending on the operation mode

For an optimal operation of the OH truck, the OH truck driver needs – compared to a conventional truck driver – further information. Figure 2 shows that this information can be received from the environment as well as from the OH truck. The OH truck driver needs information from the environment on the location, the availability, length and the provided energy of the catenary system. Besides common information on fuel rate, the OH truck driver needs information from the OH truck about the average and overall fuel usage, the battery status, the electric range and the pantograph status. By including this additional information, it is the OH truck driver's task to influence the vehicle based on his preferences. This is considered in the decision-making process of the driver, starting with the information reception. Thereafter, the information is processed in the evaluation stage, where the driving experience plays an outstanding role. Based on thinking and decision processes, the driver selects an action. It is expected that these operation mode changes can have positive and negative implications, e.g. the better the driver understands the OH truck operation, the better is his influence on the vehicle operation performance. These implications, as well as the influence of driver assistant systems, are not covered in this paper, but will be part of future research activities. Major research results regarding influences of driver behaviour on OH truck efficiency could be the basis for setting up driving recommendations in a later stage. Furthermore, such investigations will be a basis to develop a fully automated selection program for the OH truck operation modes.

The final contribution will cover more details on the data of the performed drives as well as other results.

Acknowledgments

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Authors

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	Regina Linke (27) is a research associate at the Institute of Transport Planning and Traffic Engineering at TU Darmstadt focusing on projects related to the eHighway system. After finishing her Bachelor's Degree at Johannes-Gutenberg-Universität Mainz in Business and Economics she focused with her Master Degree in Traffic and Transport Engineering at Technische Universität Darmstadt on transportation and freight transport. Within the ELISA project, she is investigating the effects of Overhead Hybrid trucks on logistic processes, the correlated cost and the acceptance by transport companies.
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