# Chapter 3
# Increasing Energy-Efficient Driving Using Uncertain Online Data of Local Traffic Management Centers

**Per Lewerenz and Günther Prokop**

**Abstract** The main goals of today's research and development are leading to different systems and topics for more energy-efficient technologies in powertrains and intelligent driver assistance systems. The funded project "Energieeffizientes Fahren 2014" (EFA 2014/2) aims for increasing the electric vehicles' operation range. In order to reach this goal an approach has been chosen which includes infrastructure data using Vehicle-to-Infrastructure (V2I) communication technologies. Particularly traffic actuated traffic lights are being utilized since this is state of the art to optimize traffic flow. Based on the interaction between vehicle and infrastructure the driver will be able to achieve an energy-efficient manner of driving through additional information and integrated board aggregation. This approach has been successfully tested in Dresden.

**Keywords** Traffic management • Communication • Car2X • HMI • Energy efficient • Microscopic traffic simulation • Dresden

## 3.1 Motivation

Individual vehicle traffic is increasing constantly and with this emission, which leads to higher environmental pollution. In order to reduce increasing emissions due to road traffic, electric vehicles are being utilized. The disadvantage of these vehicles is the relatively short range of operation. The Research and Development (R&D) project EFA 2014/2, funded by the Federal Ministry of Education and Research aims to increase the range by adapting energy-efficient driving behaviors, e.g. precise speed recommendations while approaching a traffic light. Therefore an advanced driver assistance application has been developed. It comprises the interaction between a vehicle and its surroundings—especially

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traffic lights—based on Vehicle-to-Infrastructure (V2I) communication since speed recommendations are only possible by knowing upcoming signal states of the traffic lights ahead.

## 3.2 Online Infrastructure Data Sources

Traffic management actions require a lot of information that can be obtained e.g. from induction loops, cameras and floating car data (FCD). Utilizing this detected data, infrastructure components as traffic lights or variable message signs can be influenced and adapted in order to affect the current traffic flow. Since energy consumption is dependent on traffic flow, which is mainly controlled by traffic lights in urban areas, it is necessary to understand how traffic light controls work. A new approach is being established which aims to change the behavior of a single vehicle instead of the traffic flow. Therefore the ascertainment of an individual energy-efficient driving behavior for every single vehicle is being pursued depending on traffic signal states. Signal times and delay times, as the most important characteristics, are being presented in the following chapters.

### *3.2.1 Prediction of Signal States*

In order to determine an energy-efficient driving behavior while approaching a traffic light, it is essential to know the signal state at the time the vehicle reaches the stop line. This implicates the necessity of predicting future signal times. Since most of the existing traffic lights are traffic actuated, signal times are not fixed and the use of probability based methods is required (Krumnow 2012). Traffic actuated traffic light controls contain different signal programs depending on traffic demand which varies from morning over midday to evening hours (Fig. 3.1).

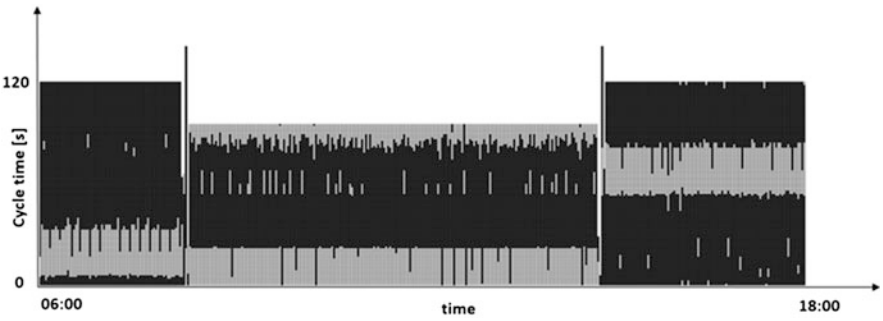


**Fig. 3.1** Signal states of a traffic actuated signal program

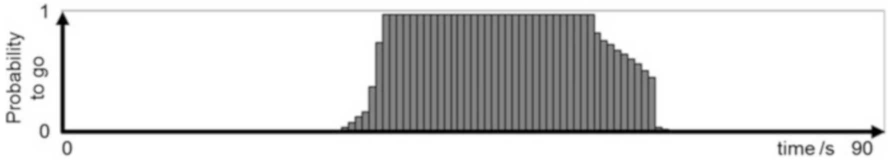


**Fig. 3.2** Example of “probability-to-go” values

Within these signal programs it is possible to request additional phases for public transport or little frequented directions causing shifted signal times.

To ascertain the predicted probabilities to go, signal states are being simplified to only two states and coded in binary vectors. Therefore, “0” relates to the states red, amber and red-amber, and “1” refers only to the state green (Krumnow 2014). This vector composed over a time period of several minutes is being transmitted to the vehicle where energy-efficient driving behavior is being computed (Fig. 3.2).

### *3.2.2 Delays Due to Traffic Light Signals*

Another important fact is the knowledge of congestion in front of traffic light controlled intersections. There are only limited possibilities measuring the queue length, e.g. with cameras, so it is more common to estimate the values of queue lengths. The used estimation procedure depends on the disposability of data sources. Statistic and heuristic methods are being applied in case only historic or aggregated data is available. If data of fixed detectors e.g. induction loops are available, approaches like the method of Mück (2002) can be utilized.

If mobile sensors like floating car data are the basis for the prediction, the method of Neumann (2011) can be applied. Within this project static sensors are being used in order to estimate delay time in seconds and queue length in meters. Both values are being updated every second. In addition to signal times, also congestion affects the traffic light control so that the knowledge of queue length and delay time is essential.

## 3.3 Communication Chain and Car Positioning

This part describes the fundamental and technical challenges within the communication chain from traffic lights into the vehicle. In Particular, this includes the latency of required information between the traffic lights and the car. Furthermore the direct conjunction of the vehicle position and the suitable information in urban scenarios is also a challenge.

These aspects can be well explained by the following example of a driving situation at a multitrack intersection in an urban scenario. The vehicle positioning solution based on GNSS is too vague for accurate localization caused by strong multipath urban environment. Due to this, the positioning solution does not allow a relation to the real driven track. In this case, the car computer does not discern which traffic light information (e.g. red or green remaining time) should be displayed for the driver. That said, the driver gets all possible traffic light information and needs to choose the right one. To avoid this, a track selection is needed. Furthermore, the displayed traffic light has to be the right one. In order to do so, the whole technical system has to handle the delayed information over the complete communication chain between traffic light and car.

For communication different types of systems (e.g. GSM/UMTS) and protocols (e.g. TPEG TSI—Transport Protocol Experts Group Traffic Service Information) are used. A complete reproduction of the communication chain in a laboratory allows simulation and measurements of the latency between different parts of the chain. Therefore, testing of different latency time measurements and interference scenarios and their solutions for communication becomes possible.

Two approaches, Kalman- and Particle-Filters, have been examined for car positioning. These two filters are state of the art (Bar-Shalom et al. 2001) and were combined with an enhanced digital map and preprocessed video data (Gosda et al. 2013).

The video data contains information about distances to the left and the right lane marks. Furthermore, the enhanced digital map provides all lanes for the test scenario in Dresden with additional information like stop markings. This information is deposited as an XML scheme and can be easily virtualized, combined and overlain with other maps. Figure 3.3 gives an overview of the used car sensors and sensor data. The data is provided via CAN bus to the car computer and is synchronically sampled for the filters. The idea is to run two filters in parallel for using

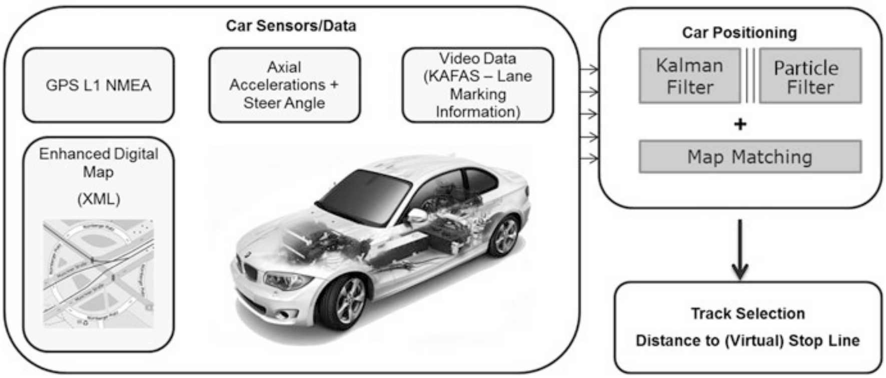


**Fig. 3.3** Overview of car sensors/data (KAFAS—Camera Assisted Driver Assistance System, NMEA—National Marine Electronics Association) and the positioning algorithms for track selection and distances to (virtual) stop lines

estimated solutions for track selection. Combined with additional video data, different hypotheses for lane selection will be examined based on the enhanced digital map. In order to assess the performance of these methods, synthetic data for filter calibration is used at first. After that, real data from the test scenario environment is used for validation. Due to this, a precision ($\leq$0.5 m for $\pm 2\sigma$) can be achieved for car positioning in case of the test environment in Dresden. The value $2\sigma$ means the probability of the positioning values is better or equal than 0.5 m in 95.4% of cases. In 4.6% of the cases the probability of the positioning values is worse than 0.5 m.

## 3.4 Real Traffic Investigation

This chapter shows the way how traffic information presented above can be displayed in a real vehicle to the driver, leading to optimal driving behavior.

### *3.4.1 Experimental Vehicle*

To validate the developed measures in real traffic, an experimental vehicle is used. This is a full electric car manufactured by BMW called ActiveE. A picture of the vehicle can be seen in Fig. 3.4. It is a converted BMW 1 Series Coupe (E82e). The electric motor drives the rear axle with a maximum power of 125 kW. The vehicle has a lithium-ion-battery with a capacity of 32 kWh which lasts for driving ranges up to 160 km.

The experimental vehicle is modeled in MATLAB/SIMULINK, to have the opportunity to simulate the energy consumption of the vehicle at different traffic conditions. Additional information on the model can be found in Schubert et al. (2014).


**Fig. 3.4** Experimental vehicle with in-vehicle measurement system

### *3.4.2 Human Interaction*

By merging vehicle internal and infrastructure information in future driver assistance functions, the amount of information for drivers will increase significantly, as the present research project shows.

It is important to make sure that the information does not demand too much attention from the driver (Winner et al. 2012). Furthermore, it should be noted that due to the source, the information will not always be reliable. Therefore, the forms of representation must be chosen so that the driver assesses the information as helpful even if they are uncertain. This means that the form of representation has a significant impact on the overall acceptance of the system. The approaches are shown to communicate uncertain information for efficient driving in traffic light approach situations to the driver. As information channels a visual display in the dash panel and haptic feedback via an active accelerator pedal are used. The installed dash panel of the used test vehicle can be programmed to flexibly examine different forms of representation. Near-series illustrations are presented to the driver and the impact on driver behavior through prototypical auxiliary displays can be avoided. With help of the active accelerator pedal, the counter force, which the driver has to apply to the operation of the pedal, can be varied dynamically. On the one hand, a direct influence of the driver can be initiated; on the other hand, the driver's attention can be stimulated by vibrating the accelerator pedal. For the optical information two areas were defined in the display. One area is used for the recommendation, and the other one for information (Fig. 3.5).

In the area of recommendation a range of traveling speed is recommended. With the recommended speed, the next traffic light is reached at a green phase without vehicle standstill. The quality of information is taken into account that a distinction is made between the core times (probability-to-go > 90%) and a region of high probability (90% > probability-to-go > 70%). The representation in the information area depends on the current speed relative to the recommended speed. Therefore, the consideration of information quality in the information area is set automatically. If the speed of the vehicle is below a certain level (10 km/h), the remaining phase duration is displayed. The assignment and the information displayed are shown in Fig. 3.6.

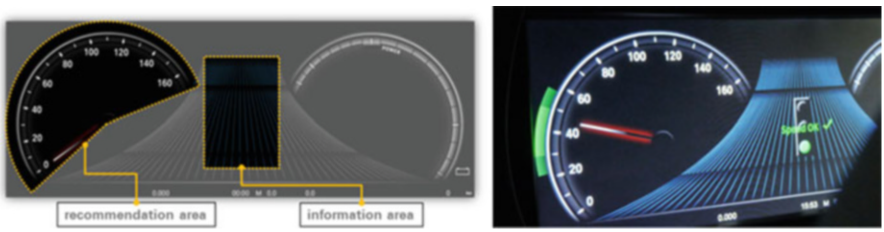


**Fig. 3.5** Programmable digital instrument panel

Matching the information of the different areas, the active accelerator pedal is triggered. In cases (1) and (5) the driver is informed by a slight vibration of the pedal that he should optimize its longitudinal dynamic behavior. In cases (2) and (4) the driver is caused by the increase or decrease of the pedal counter force to change the speed to the optimal range.

### 3.4.3 Validate the Benefit of Driver Assistance in Simulated Traffic Scenarios

To get reliable results while validating the effect of driver assistance systems in real traffic a huge amount of test kilometers is necessary. Simulation is a very powerful way to analyze these systems.

Current researches in Bley et al. (2011), Schubert (2010) and Schuricht et al. (2011) in the context of traffic light assistance systems (TLAS) and predictive cruise control systems (Asadi and Vahidi 2010) show the high potential of driver assistance systems to realize an energy efficient driving behavior. All of these systems use the information of traffic lights to calculate an optimal velocity to approach the intersection. Consumption reductions between 3% and 5% (Bley et al. 2011) and in some situations about 30% (Schuricht et al. 2011) in comparison to the uninformed driver are shown. For a general declaration it is essential to examine the influence of other road users, in particular the queue length, at the stop line of traffic lights. Currently the scenarios examined are only very simple traffic situations (e.g. one lane, static traffic light programs).

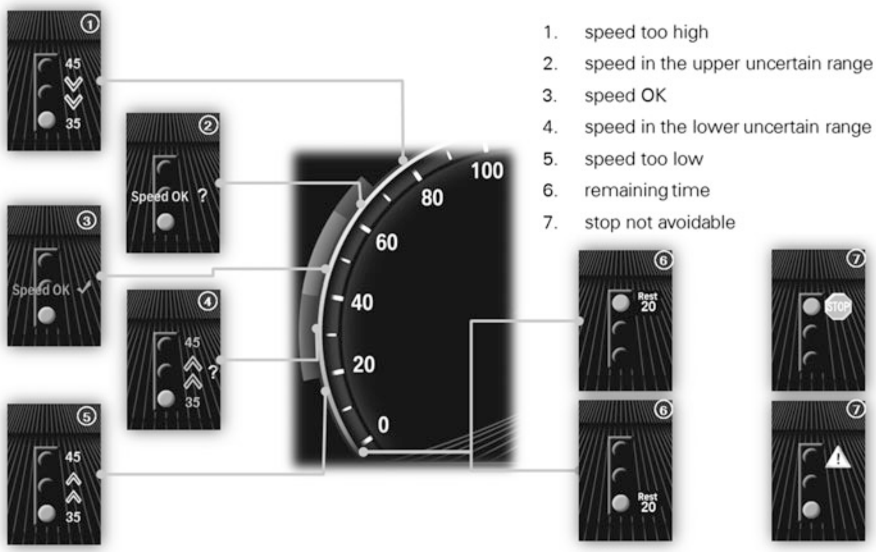


**Fig. 3.6** Assignment of information and recommendation

To simulate more complex traffic scenarios a new simulation framework (Schubert et al. 2013) was developed. It is an interface between detailed nanoscopic vehicle simulation with MATLAB/Simulink and traffic flow simulation with SUMO (Simulation of Urban Mobility). With different parameters like speed limits, traffic light control, number of lanes, and density of traffic flow, the impact of different traffic situations on the energy consumption can be determined. For that purpose a vehicle model (see Sect. 3.5) is used to determine the energy consumption. Different traffic scenarios and their influence on the individual energy consumption are analyzed. The results will show whether these systems are useful and how beneficial it is.

## 3.5 First Results

In a first realistic use case the potential of the traffic light assistant TLAS is shown. A part of an urban route in Dresden with a constant traffic stream is modelled in the SUMO Simulation suite. On basis of Asadi and Vahidi (2010) a traffic light assistance system is implemented in MATLAB and simulated with the framework described in Sect. 3.4.3. Different parameters e.g. the time of occurrence of the analyzed vehicle are varied.

Besides the reduction of vehicle stops and trip time the energy consumption of a vehicle is important. It is calculated with a model (Schubert et al. 2014) of the described vehicle (see Sect. 3.4.1). Figure 3.7 shows the trajectories of a vehicle for different times of occurrence in the provided road network. Evidently, some of the vehicle stops can be prevented.

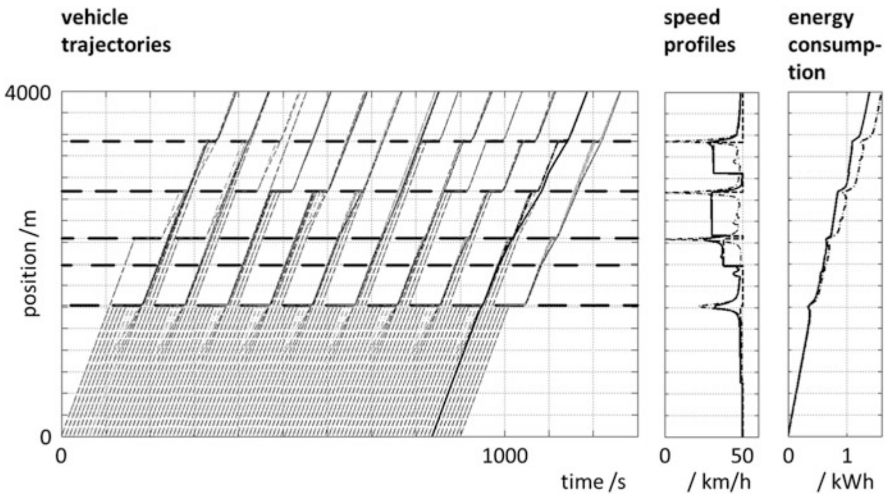


**Fig. 3.7** Simulation results: vehicle trajectories, detailed speed profile and energy consumption

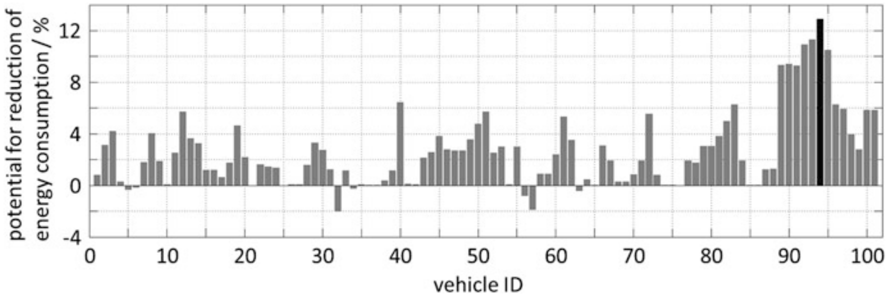


**Fig. 3.8** Simulation results: energy consumption of simulated traffic situations. Vehicle 94 is highlighted with the best potential

The consumption for each of these vehicles can be seen in Fig. 3.8. The highest potential for energy consumption is provided for vehicle number 94. Although there are obviously some disadvantageous situations that could cause higher energy consumption (see vehicles 32, 56 and 57 in Fig. 3.8).

These are caused by the effect that in some cases a vehicle with TLAS could pass the next traffic light but this leads to a disadvantageous situation at the next traffic light, so the TLAS cannot avoid the vehicle stop. This demonstrates the need of further research on that topic.

## 3.6 Conclusions

The R&D project EFA 2014/2 is pursuing the approach to obtain infrastructure information of the whole road network, e.g. traffic light information. This information is being broadcasted using the widespread and available mobile communications network. This involves assets and drawbacks, e.g. concerning the availability and higher latency times compared to usual directional connections between car and traffic light. In urban areas traffic actuated traffic lights are being utilized now and in the future even more. These traffic light controls are being influenced by traffic flows as well as single vehicles so that it is possible to react dynamically to varying traffic demands. Due to this variation, only a prediction approach is capable. In doing so, it is necessary to create an approach that is able to deal with probability-based values.

Results of various simulations show an energy-saving potential of about 10% by using this developed approach. To investigate the approach in real traffic, a test vehicle was equipped with the system. Therefore, a special display has been developed that is able to deal with probability-based values. In order to achieve the desired driving strategy the driver is being supported actively by the system. On the one hand, the driver gets driving instructions via a display; on the other hand, an onboard unit pays attention to an efficient realization of these instructions. Finally an energy-efficient approach has been created to increase the range of electric vehicles which is transferable to other cities.

In future, needed data streams can be distributed over different communication systems. Therefore, non-time-critical information (e.g. map data) can be distributed by broadcast. For time-critical information (e.g. short-term prediction data) it seems to be suitable to use communication systems with low latency. The state of the art is to optimize driving strategies while approaching single traffic lights. Considering all traffic lights on a route may lead to even higher saving potentials. Also the developed energy-efficient driving strategy needs to be adapted to these new conditions. Nevertheless, it is conceivable that a wide transmission of signal data can lead to a global optimum regarding to the driving strategy for the whole route.

An important point is that driver assistance systems will capture the infrastructure more effectively in future, but also the infrastructure systems will react smarter to the traffic.

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