Evaluation of Traffic Control Systems as ITS Infrastructure for Automated Driving

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Abstract. Vehicles with automated driving systems require more sensor information about their environment than non-automated vehicles. Detection with camera, lidar or other sensors is already state of the art in newer vehicles. As of today though, they only work in close proximity and lack the incorporation of existing traffic information from local authorities.
In this paper, we present a novel way of providing traffic management information to vehicles, sent directly from Road Authorities. We use existing ITS (Intelligent Transport Systems) infrastructure and assess how information on traffic control and re-routes, displayed on variable message signs, can be used as sensory input for vehicles.
We examine real world data from a South German Road Authority. The evaluation of latency, reliability and integrity of traffic information has been conducted end-to-end as well as between the six stations that are involved. We show the general feasibility of our proposal and discuss which obstacles need to be overcome for a wider use in other road systems.

Keywords: ITS infrastructure · Traffic management information
Automated driving systems · Traffic Control Systems

1 Introduction

The arise of highly automated driving requires accurate information about the vehicles environment. In current practice, each car detects its surrounding solely by its own sensors, like camera, lidar and radar. Much research has been conducted on sensor evaluation, including reliable detection of static traffic signs [1,2] even in challenging weather conditions [3]. These approaches focus on the visual detection of displayed information. However, traffic data is also transmitted via cellular communication or as fallback solution via RDS (Radio Data System) TMC (Traffic Message Channel), informing about road conditions, traffic congestion or construction works. Why not use existing infrastructure as an additional virtual sensor to deliver traffic control input into vehicles?

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Currently, human drivers are confronted with two different traffic control information: one from their in-car navigation and one from traffic signs on roads and highways. Both information can differ in content. The car sensors might detect a static traffic sign but leave the information from a variable message sign (VMS) aside. This can lead to information inconsistency which is bothersome for drivers and can be critical, when it comes to higher automated driving.

In this paper, we introduce a novel way to provide traffic control and re-route information to vehicles. The main goal is to keep the content aligned on VMS and in the vehicle. We focus on how the existing infrastructure and standardized data formats can be re-used because minimizing costs plays a major role in the success of further automation. We investigate Traffic Control Systems (TCS) in South Germany and evaluate the information sent to each VMS and forwarded to the vehicle.

The following Sect. 2 provides a brief background on the existing infrastructure of the investigated highways and the system architecture. Related work is presented in Sect. 3. In Sect. 4 we introduce our approach, explain the data formats as well as the matching algorithm. An evaluation and discussion of results is provided in Sect. 5. We conclude our work with Sect. 6 and give a brief outlook to next steps.

2 Traffic Control System (TCS)

The term ITS refers to various kinds of traffic, transport and information systems. In this project, we focus on one area: Traffic Control Systems that enable VMS on highways to display important traffic information. We investigate two kinds of information displayed, using two different display technologies:

1. Lane control signs with LED displays,
2. Re-route signs with fixed content prisms.

2.1 Lane Control

Lane control signs (LCS) are message signs that manage traffic on multi-lane roads or highways. Signals include speed limits, warnings or prohibitions to control traffic on this highway. Usually lane control signs are installed at the side or above the highway. If above, signs are placed over every lane to display lane specific information such as lane availability or speed limits. Additional signs between two lanes display further information such as end of no overtaking (cf. Fig. 1(a)). Usually lane control signs use LED technology, to allow good visibility and quick changes.

2.2 Re-routing

Re-routing signs (RRS) present drivers with viable alternate highway routes. The alternate routes are disseminated on prismatic variable message signs.

One VMS can consist of several prisms. Each prism is turned individually to one of its three sides (cf. Fig. 1(b)). Most often, several prisms need to be turned for one route change, to keep re-route information aligned. This may take several seconds due to the mechanical process of turning.

(a) Lane Control Signs (b) Re-Route Signs

Fig. 1. Variable Message Signs (VMS) on a German highway (Source: Bavarian Road Administration).

2.3 Origin of Information

The information displayed is generated by infrastructure operators from Road Authorities. They use historic traffic patterns to predict traffic situations. Real time traffic data, from video monitoring, is added to verify prediction and react to special traffic situations. Both data combined create the basis for lane control and re-route plans. Speed limits may reduce traffic speed during peak hours to avoid traffic jams. Re-routing is applied to spread traffic to less crowded highways or roads. Unfortunately, this information is only provided on VMS and communicated via web or radio (RDS TMC). Current navigation systems do not consider these re-route advises from Road Authorities and do not receive information on speed limits and warnings displayed on LCS. This leads to inconsistent information in vehicles on both, lane controls and re-routes.

3 State of the Art

Present methods of in-car traffic information refer to visual analysis. Traffic sign detection has been an active research topic in the last decade. Various approaches of static traffic sign detection have been conducted. In general, they use color and shape detection [4], reaching top performance, as summarized in [1]. Most often they are above 90% [2] detection rate, even in challenging conditions. Benchmark data have been created for several European countries [3,5] and the US [6] to test and train the approaches. However, all research focuses on static traffic signs.

Other approaches investigate the use of wireless communication for transmitting traffic control information into vehicles. One of the first projects, in this field, was COOPERS (Co-operative systems for Intelligent Road Safety) [7].

Within this project, different transmission technologies, as DAB (Digital Audio Broadcast), DVB-H (Digital Video Broadcast - Handhelds), 802.11p and others have been evaluated for broadcasting information. Similar to our approach, they have built on existing traffic infrastructure. The aim was to exchange local traffic and safety related information, e.g., on accidents, weather conditions or lane utilization in real time to enhance road safety.

For a consistent transmission of VMS information to relevant vehicles a standardized message format is defined in ISO/TS 19321 [8]. Within the project ECo-AT, closely related to the presented solution in this paper, the standard will be implemented from 2017 to deploy the In-Vehicle Signage (IVS) use case at the Austrian section of the European Corridor [9]. Thus, comparable results about communication latency are not available from that project yet.

One approach, very close to ours, is the VINCI application [10]. As we, they wanted to avoid inconsistency between the information provided at VMS and in the vehicle. A mobile application continuously tracks a vehicles position and sends the information to Road Operators. In return, the application receives information about the local traffic situation, VMS and other location based information. This approach relies on the comprehensive use of the VINCI application, similar to Google's navigation. It, therefore, does not take advantage of existing infrastructure.

4 Approach for Leveraging Existing Infrastructure

In our approach, we investigate how existing ITS infrastructure can be used to provide vehicles with the same traffic management information displayed on VMS. The main research questions are: To which extent can we use existing communication infrastructure to deliver equal information to traffic signs and vehicles? Can we guarantee that this is conducted in an appropriate amount of time? Can we forecast how long a message needs from start to end? Or is the spread among messages too big and their arrival is unpredictable?

To answer these questions, we present an analysis of data sets received from two German highways. We examine data formats, analyze their content and calculate latency and variance. We check if latency differs during peak times or due to other circumstances. The main goal is to evaluate the feasibility of our approach which could then be extended and adopted by other ITS infrastructure in Germany and abroad. The detailed system architecture is presented in the following section.

4.1 Logging Stations

The system contains six stations. Data can be logged at reception or transmission time (or both). We analyze time stamps of receipt and content of the information sent. The investigated stations are as follows (cf. Fig. 2):

1. RASC - Road Authority Sub Center,
2. VMS - Variable Message Signs,
3. SDBS - Strategy Database Server,
4. MDM - Mobility Data Marketplace,
5. SP - Service Provider,
6. Vehicle - In-Car Mobile Device.

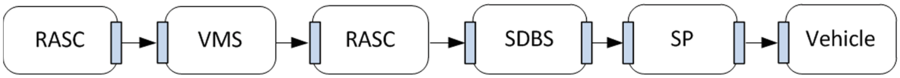

Fig. 2. Communication architecture and log stations (rectangles).

Latency and data integrity tests are conducted between all stations as well as end-to-end: starting from the Road Authority Sub Center (RASC) up to the destination node, a mobile device in the vehicle. This allows to generate end-to-end results and identify where most latency and highest variance takes place.

The starting point of all traffic information is the *RASC*. Traffic information is created by individual Sub Centers of the Road Authority, each being in charge of a specific highway section. Messages are sent from the RASC server to the corresponding traffic signs using *TLS over IP*. Older systems still use a proprietary communication system called *inselbus* with limited bandwidth of 9600 baud. The *VMS* displays the signal using the technology available (in our case LED or prisms). An acknowledgement is sent back, once the information is displayed. In case of any failure the same information is resent. The messages are forwarded to a Strategy Database Server (*SDBS*), where all displayed traffic data is stored in a relational database.

The SDBS sends the TCS information to two successors: the Mobility Data Marketplace (*MDM*) - a national access point to provide traffic data to public services [11], and a Service Provider (*SP*) - which uses the data for proprietary services it offers. In our test scenario, the SP forwards the data to a distinct single mobile device in a vehicle which subscribes itself to the service.

4.2 Data Formats

Throughout the communication chain data sets vary in format and content. Three data formats are included: 1. WanCom, 2. DatexII, 3. JSON. The first three stations (RASC, VMS and SDBS) utilize the standard *WanCom*[1] format for data description and communication. It was never intended to be used externally. The transmission to external users is therefore conducted in the *DATEXII* [12] format, a standard created by the European Commission, for external use. The SDBS receives data in WanCom and forwards them in DATEXII. The Service Provider receives DATEXII content, stores the information for further use

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[1] An industrial standard with internal specification only.

and sends a reformatted set of data in *JSON (Javascript Object Notation)* to the mobile device in the vehicle. The JSON format has been defined specifically for this project and may change in future or following projects.

4.3 Unification of Heterogeneous Data Sets

In order to track and match the heterogeneous data sets, we needed to create a comparable format to which all original data must be transformed.

Data Transformation. Data transformation is conducted in a joint two step process: *Filtering* and *Parsing*. Because the received data sets contained non-relevant data, we filtered those first, leaving only data relevant to the vehicle. Examining the raw data revealed that each data format contained a different amount of information. The set of information is not comparable to one another. Some information from the WanCom format is not found in the DatexII format and vice versa. The final comparable format is limited to content available on both, WanCom and DATEXII. The JSON data contain an identical set of information, as we created it specifically for this purpose.

Data Matching. The investigated ITS infrastructure was not designed for communication outside of traffic management. Matching data over all stations became the major challenge as messages did not contain unique IDs. To indistinguishable identify a message, we needed to create a key using information available in all log data. After a qualitative analysis, we extracted four keys: traffic sign identification (node number), channels (what type of traffic sign is expected and above which lane it is placed) and the content displayed. The forth part needed to be the time stamp. Some information is displayed repeatedly within a day, at one station, on one channel and with the same content. We therefore included log times, when a station receives the information from its precursor or (if available) the time when the information was displayed on the VMS.

A corresponding data set is only searched at a following station if the time stamp of receipt is within a pre-defined time offset. Manual tests showed that traffic signs (especially lane control) change frequently to the same content. Thus, the offset needs to be lower than a possible repetition. Re-routes change less frequent. Therefore, we use an offset just below their repetition times. For validation purposes, we carried out quantitative and qualitative comparisons of false positive results with varying offsets. Even though much effort has been made, our matching algorithm cannot guarantee a match being perfect. It, however, is sufficiently reliable for our purposes of a first test.

5 Analysis and Evaluation

To proof the feasibility of our approach, to align information in vehicles with those on VMS, we conduct a field test. We analyze data sets recorded by the Road Authorities, the SDBS providers and the test application in the vehicle (see Fig. 3). All data are recorded on May 23rd, 2017 along two highway sections in South Germany: (1.) highway A9 close to Nuremberg and (2.) highway A9 and A92 north of Munich.

Fig. 3. Test application in vehicle displaying the same VMS as on the road (Source: Bavarian Road Administration).

Test Setup. Over 8000 messages were sent from the RASC to the VMS. We extracted 3130 messages for lane control and 32 for re-routes. This data provides the basis for the analysis on latency, data integrity and reliability. The remaining information is irrelevant for our inspection as it contains weather and light information or data duplicates.

Earlier tests have revealed problems which led to unusable results. The main challenges resulted from two issues: non NTP (Network Time Protocol) synchronized stations and data duplicates. The frequency of NTP synchronization varied from station to station - reaching from every other month to each day. This led to changing latency in results among test days. A consistent time interval for NTP synchronization provided more homogeneous latency results. The data duplicates have been identified as a result from messages that were resent once a failure occurred in the acknowledgement. Redundant content was provided to the VMS to ensure the information is displayed properly. However, if both the initial message and the re-sent one reached the VMS (and only the acknowledgement failed), we received two data sets with the same content and within the preset time offset. This led to unexpected latency. A unique ID would have helped to solve this challenge. We solved the issue by using the first-in-first-out-strategy.

Results. We analyzed data on lane control and re-routes. We conducted separate analysis because both data differ in communication technology and content. Also the total amount of messages differ significantly. Re-route messages are fairly lower in quantity as the information has to be displayed longer and is changed less frequent to allow efficient traffic flow to evolve. Speed limits, prohibitions and warnings are changed more often during business hours and whenever incidents happen to keep traffic safe and at optimal speed.

For lane control signs we identified an *average end-to-end latency of 7.1* s. In depth investigation reveals that highest latency and biggest variance is created in the first step from RASC to VMS (see Table 1). This is because more than one service is conducted on the RASC server and other services might delay the TCS messages. Reducing the services running or giving TCS messages priority is important to lower latency and make it more predictable. Communication through the remaining stations takes 4.4 s in average and show less variance. This time needs to be taken into consideration to keep information aligned for vehicles and road signs. Otherwise, drivers or higher automated driving systems could be left with ambiguous information at some times. As the VINCI application (presented in Sect. 3) provides similar VMS data to vehicles it would be interesting to see if their approach provides information faster. Unfortunately, the report did not contain results on how long it takes to receive the vehicles position and display the local VMS data.

Table 1. Latency in seconds for LCS and RRS data sets from May 23rd, 2017.

Data/to station	VMS	RASC	SDBS(in)	SDBS(out)	SP(in)	SP(out)	Vehicle	Sum
LCS - MEAN	2.7	0	1.6	1.5	0.4	0.4	0.7	7.1
LCS - Variance	1.7	0	0.5	0.9	0.9	0.2	0.5	
RRS - MEAN	9.8	1.8	1.3	2.9	0.2	0	0.6	16.6
RRS - Variance	3.6	0.4	0.5	1.3	0.2	0	0.3	

Latency on re-route signs (RRS) is significantly higher compared to LCS. Messages needed *16.6* s end-to-end in average. The increase in latency may result from two issues: First, the mechanical turn of the prismatic sign takes longer than LED sign changes (see Sect. 2). Second, the communication standard used for the examined re-route-signs is older and messages are sent with 9600 baud over inselbus. The very small data set can, however, only give an indication and results cannot be compared one by one to LCS latency. Further test are needed to allow a reliable quantitative analysis. But there is indication that most latency arises between RASC and VMS and least latency takes place after transmission of the Service Provider.

One goal of our analysis was to determine, if arrival times can be predicted or if the spread is too high. Typically, we found that lane control messages arrive at the vehicle within *4 to 9* s (cf. Fig. 4) with a very small deviation at the upper and lower bound. This does not change at traffic peak times or among VMS. 96.8% of the messages tracked at the RASC reach the VMS within an offset of 20 s. Therefore traffic control messages are very reliable. Re-Route messages have a wider range of time - most often between *10–20* s, evenly spread. Within

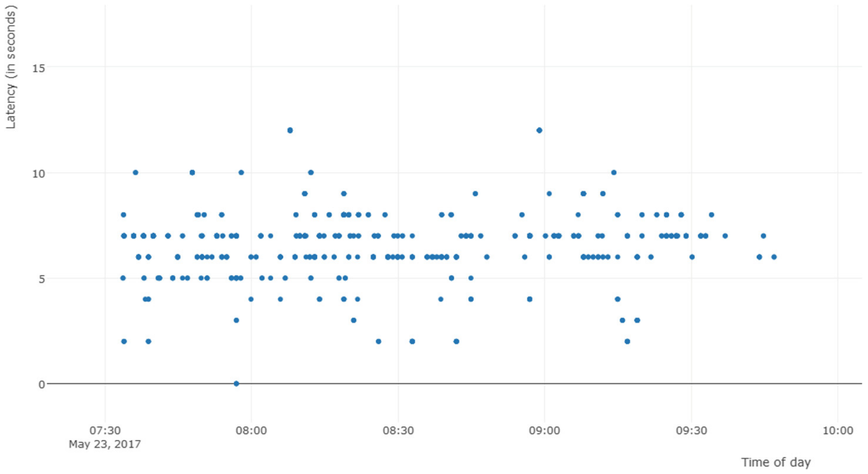

Fig. 4. Overview: latency of LCS for end-to-end communication.

the offset of 30 s only 75.3% of the messages arrive at the VMS. Lane control information seems not only to be provided faster but also more predictable than re-routes (even though we cannot compare them on a quantitative basis). The faster communication standards (*TLS over IP*) and the quicker signal change with LED might influence the predictability. As naturally anticipated, we can affirm that communication infrastructure can be taken best, if newer technologies are used. If, further on, servers at the RASC (related to TCS) are used exclusively for this purpose, the latency from RASC to VMS can be lowered significantly. We are able to forecast how long expected end-to-end transmission takes, but there is still potential to lower times. However, we have found that data is transmitted with high integrity and thus, vehicles could rely on the messages received.

6 Conclusion

In this project, we examined if existing ITS infrastructure could be leveraged to provide the same traffic control data to vehicles as displayed on VMS. We examined data recorded from two highways in South Germany and evaluated data first qualitative to gain an understanding of the data sets and their challenges and then quantitative to calculate latency and reliability.

We found that even though the infrastructure was never designed for this purpose, it is possible to re-use existing traffic control systems to align in-car information with VMS. Especially, if modern technology for displays (such as LED signs) and advanced communication technology (such as TLS over IP) is used, the latency would become even more predictable.

Our evaluation showed that heterogeneous data formats, infrequent server time synchronization and missing message IDs are major challenges that needed to be overcome for the feasibility of this approach. We are looking forward to see results from other RASC in future as infrastructure and data formats differ from highways and countries. It can be possible that the results are influenced by the specific communication architectures and therefore lead to varying results.

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