DETECTING INCIDENTS WITHIN TRAFFIC FLOW IN TUNNELS BY VEHICLE AND INFRASTRUCTURAL BASED DATA

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ABSTRACT

This paper will give an overview about the latest research results of the company ave in the field of detecting incidents within traffic flow in road tunnels by vehicle and infrastructural based data. The presented approaches and results were mainly gained in the context of the research project "**Ko**operative **Mo**bilität im digitalen Testfeld **D**üsseldorf (**KoMoD**)" funded by the Federal Ministry of Transport and Digital Infrastructure (BMVI), Germany.

Due to further technical developments regarding intelligent transport systems and vehicle technology the amount of available traffic data increases rapidly. This applies to the entire road network including its safety-critical parts for example like road tunnel.

Within the two year project KoMoD (2018-2019) the Rheinalleetunnel in Düsseldorf was equipped with a state of the art infrastructure based traffic measuring system called MAVE®-tun and with communication systems to collect and spread traffic data between vehicles and infrastructure via cellular and Wi-Fi communication. The traffic data captured this way was merged in a data concentrator to get enhanced traffic information, which was given to the tunnel control center. At the tunnel control center the enhanced traffic information was verified and transformed into corresponding messages. These messages were given back to the vehicles via various channels.

Using the respective advantages and particularities of both, the new available vehicle and the conventional infrastructural based traffic data as well as of the Vehicle to Infrastructure (V2I) communication technologies, the gained results of the research project KoMoD are promising.

The results show that incidents and abnormalities within the traffic flow in tunnels can be detected faster and more detailed. Moreover, the spread of traffic information is no longer tied to special display cross-sections at least for the equipped vehicles.

These promising results led to a further funding of a new two year follow-up research project called KoMoDnext (2020-2021).

Keywords: *Vehicle-to-Infrastructure, V2I, Car-to-Infrastructure, C2I, vehicle based traffic data, infrastructural based traffic data, KoMoD, KoMoDnext, ITS G5, 5G, tunnel, reliable traffic information, incident detection*

1. INTRODUCTION

The amount of vehicles that communicate with their environment increases rapidly, not only in Germany. In particular, most recent vehicles that are able to drive at least (partially) automated usually have the corresponding technologies. It is assumed that this development will increase in the near future. At the same time, conventional vehicles, i.e. vehicles that do not communicate with the environment, will continue to use the same road infrastructure. This is leading to mixed traffic. Currently it is not foreseeable whether or when the mixed traffic will skip into traffic that is completely connected with the environment. It is expected that mixed traffic will remain on the roads for at least a longer period of time.

Both, in mixed traffic and especially in completely connected traffic, vehicles which communicate can provide vehicle based data as so-called Extended Floating Car Data

(XFCD). XFCD is generated by on-board sensors of the vehicles to enable e.g. automated driving functions. Furthermore, this information can be also valuable for traffic flow and/or incident detection.

Besides the collected vehicle based information there is also reliable infrastructure based traffic information for many areas in the road network, which can significantly support both the driver and the automated driving functions. In particular, if this is additional information that cannot be collected early enough or at all by the driver or the automated driving function itself.

In safety critical infrastructure areas, such as road tunnels, the exchange of data and information between vehicles and the infrastructure is of particular interest. On the one hand, these areas are already well equipped with infrastructure based measuring systems. On the other hand, additional XFCD can contribute to gain even better and/or faster reliable traffic information.

Even minor incidents e.g. like an overheated engine, can easily lead to a major disaster like a tunnel fire. Passing incident locations is difficult due to the limited space. The same applies to self-rescue. Escape routes to emergency exit are sometimes longer than expected and distances towards an incident location which seems to be safe outside a tunnel, may not be safe in a tunnel.

In addition, neither a driver nor the onboard sensors of an automated driving function can oversee the whole tunnel before or at the time of entering a tunnel of a certain length. A reliable estimation of the current traffic situation in the tunnel (e.g. traffic flow, incidents) is not possible for either of them without additional reliable and early traffic information from the infrastructure.

One of the research goals of the KoMoD project concentrated on investigating an infrastructure based support of automated driving functions in mixed traffic within road tunnels.

2. DESCRIPTION OF THE KOMOD PROJEKT

The KoMoD project was funded by the Federal Ministry of Transport and Digital Infrastructure within the funding directive "Automatisiertes und vernetztes Fahren auf digitalen Testfeldern in Deutschland" with about 9 million euro. The Goal was to set up a testing area for new technologies in the field of V2I communication to support automated driving functions. During the 25-month project (June 2017 to June 2019), a testing area was set up in the Düsseldorf metropolitan area, covering motorway, tunnel, urban traffic and parking. Figure 1 gives an overview of the test field, which extends from the motorway junction Meerbusch (A44/A57) via the A57 to the motorway junction Kaarst (A57/A52) and from there via the A52 towards the city of Düsseldorf through the Rheinalleetunnel, over the Rheinkniebrücke into the city center / Friedrichstadt district. The table in Figure 2 summarizes the main information about KoMoD.

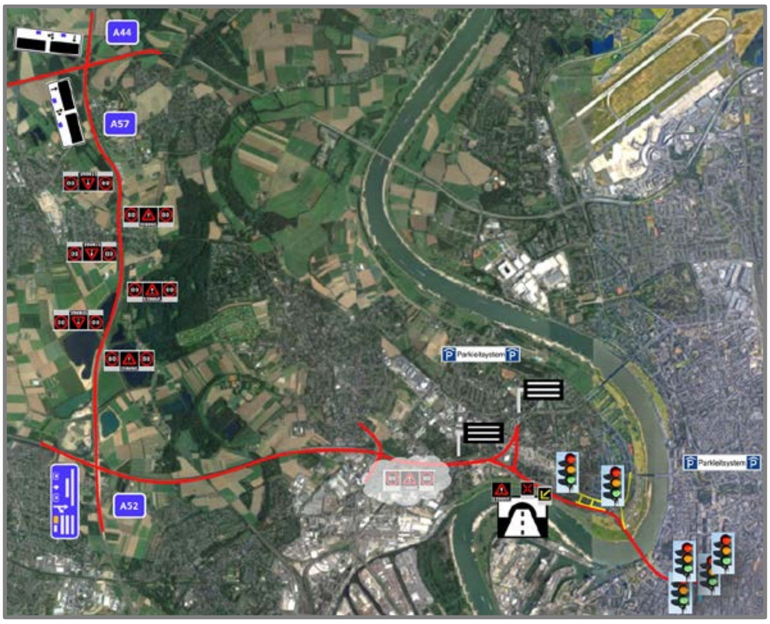

Figure 1: KoMoD - overview test field

Acronym	**KoMoD**
Full name of the project	**Ko**operative **Mo**bilität im digitalen Testfeld **D**üsseldorf
Project duration	Juni 2017 bis Juni 2019
Total cost	14.846.832 €
Funding	9.039.221 €
Funding directive	Automatisiertes und vernetztes Fahren auf digitalen Testfeldern in Deutschland
Funder	Bundesministerium für Verkehr und digitale Infrastruktur
Project Management Agency	VDI/VDE Innovation + Technik GmbH
Project partners	Amt für Verkehrsmanagement Landeshauptstadt Düsseldorf (mit der Rheinbahn), ave Verkehrs- und Informationstechnik GmbH, DLR, FH Potsdam, GEVAS Software, ika RWTH Aachen, vodafone, Mobileye, SIEMENS, StraßenNRW, SWARCO, ZF
Associated partners and subcontractors	Ford und Heusch Boesefeld

Figure 2: KoMoD - Information

3. DESCRIPTION OF THE TUNNEL APPROACH

Driving through a tunnel is a special driving task for both a driver and the automated driving function. Reasons, among others, are the changing road and/or visibility condition (e.g. brightness, weather and limited space). Automated driving functions should also be able to deal with the loss or limitation of onboard sensors (e.g. GPS) while entering a tunnel.

Thanks to the city of Düsseldorf the Rheinalleetunnel was also part of the testing area in KoMoD. For this part of the testing area the main research focuses entailed:

1. Incident detection within traffic flow in tunnels by combining vehicle and infrastructural based data
2. Providing important traffic information and warnings
    - to all vehicles (collectively) via variable message signs and/or barrier signs
    - to equipped vehicles (individually) by Road Site Unit (RSU) and/or cellular radio
    - to third parties via "Mobilitäts Daten Markplatz (MDM)"

3.1 TUNNEL EQUIPMENT

The main part of the Rheinalleetunnel is about 650m long and consists of two tunnel tubes with unidirectional traffic and two lanes per direction. Together with the corresponding entry and exit ramps it has a total length of more than one kilometer. Within the road network of Düsseldorf, the Rheinalleetunnel forms an important road connection from the west into the city center. Close to the Rheinalleetunnel the city of Düsseldorf runs a traffic and tunnel control center called Verkehrs- und Tunnelleitzentrale (VTLZ). The data from the Rheinalleetunnel (including KoMoD tunnel data) is also available in the VTLZ [Böhnke P.L. 2019].

Within the research project, ave developed and installed an infrastructure based but section related measuring system. Based on Intelligent Induction Loop technology four measuring cross sections including corresponding Route Side Stations (RSS) over a total distance of about 600m were installed in one tunnel tube (direction toward the city center). The distance between each cross sections amounts to approximately 200m. To connect the four RSS as well as the necessary sub-control center a TCP/IP network was set up. The sub-control center was located in the VTLZ. In addition, project partners established two independent ways of V2I communication. For this purpose RSUs were installed in the tunnel, which enabled a V2I communication via a form of WLAN standard (project partner SWARCO). As a second independent communication way, data could also be transmitted via cellular radio network (project partner Vodafone). Figure 3 gives an overview of the KoMoD tunnel equipment [Böhnke P.L. 2019].

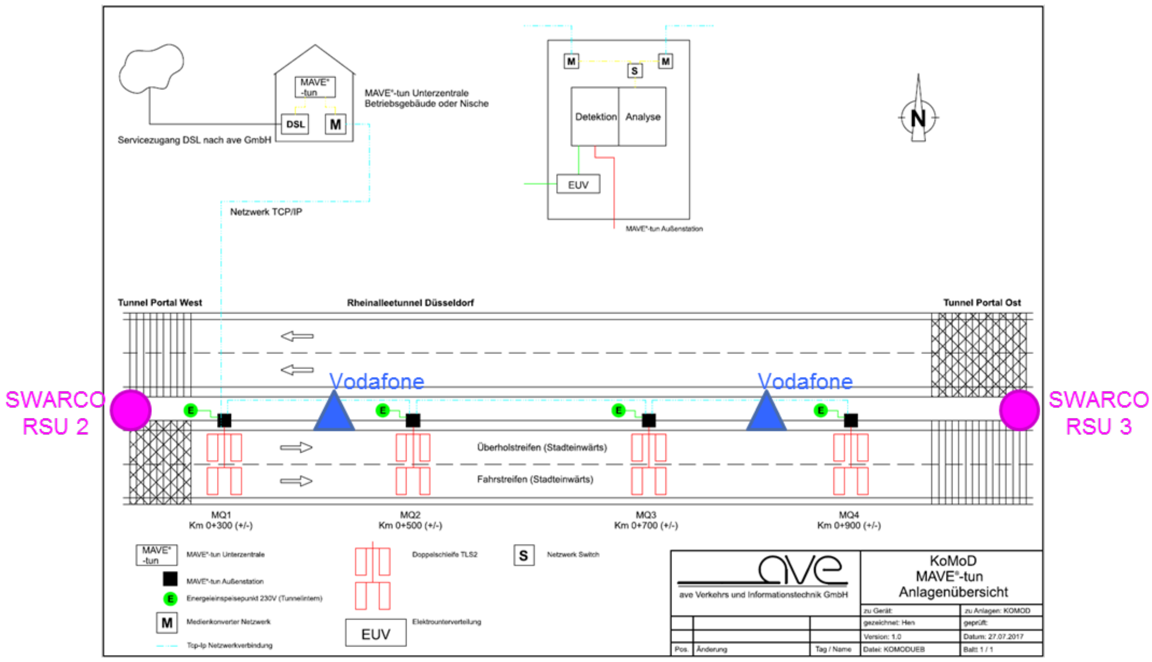

Figure 3: KoMoD - tunnel equipment

3.2 DATA BASE

Due to the selected KoMoD tunnel equipment and the structure of the tunnel testing area, it was possible to collect as well collective and infrastructure based traffic data as individual and vehicle based data.

3.2.1 COLLECTIVE AND INFRASTRUCTURE BASED DATA

To obtain continually infrastructure based collective traffic data, ave developed, planned and implemented a MAVE®-tun R&D system based on the measuring principle of the Intelligent Induction Loop. Thereby it was possible to collect both local (e.g. local speed, traffic volume and vehicle classification) and section-related traffic data (e.g. travel time, travel speed and density). For the section-related traffic data, two adjacent measuring cross-sections were logically combined into one measuring section (Fig. 4). As soon as a vehicle entered the measuring section via the entrance cross section, an electromagnetic pattern of the vehicle was recorded. When leaving the measuring section, a second electromagnetic pattern was detected at the exit cross section. By pattern recognition both patterns were correlated. An essential feature of this measuring procedure is to guarantee privacy. This means it is for system-related reasons impossible to identify individual vehicles or drivers [Böhnke P. & Böhnke P.L. 2018].
The time difference between the time stamps of the two patterns corresponds to the travel time of the vehicle. As the distance between entrance and exit cross section is structurally defined and known. Thus, the travel speed through the section can be calculated easily. Since the method is applied continuously for each vehicle, the number of vehicles in the section can also be measured. This also enables the calculation of the traffic density. All collected traffic data is available in real time.
Incidents are detected by comparing the travel time of the individual vehicle with the travel time of the surrounding traffic. Significant differences are an indicator for incidents like broken down, slow or wrong driving vehicles. All significant events cause an immediate change in the current traffic flow. Hence, the detected results indicate incidents of any cause, e.g. a car break down, an accident or a person on the road at a very early stage.

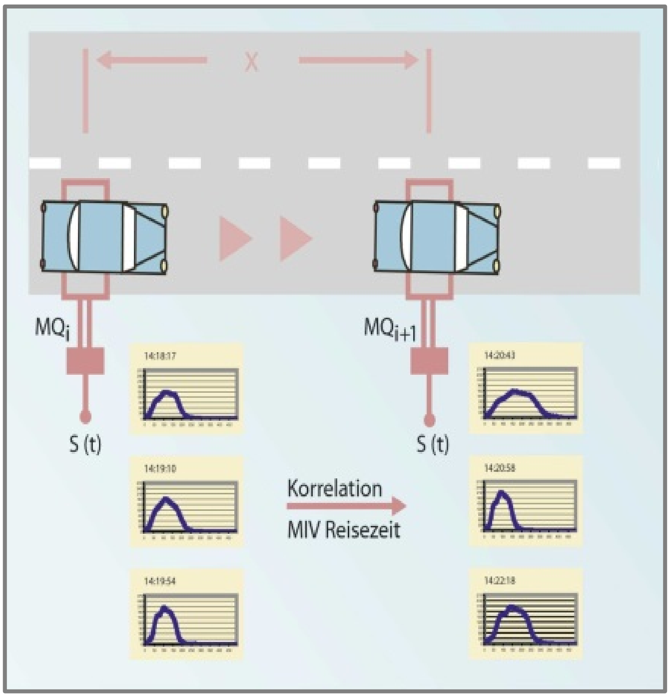

Figure 4: Intelligent Induction Loop technology - measuring principle

Due to the physical measuring principle and its implementation in the Rheinalleetunnel, the infrastructure based measurement data had a spatial resolution of about 200m and a temporal resolution that corresponds to the current travel time. The measuring method was able to detect every single vehicle. Special equipment of the vehicles regarding communication and/or onboard sensor technology, as for example for automated driving vehicles, was not necessary [Böhnke P.L. 2019].

3.2.2 INDIVIDUAL AND VEHICLE BASED DATA

To get individual and vehicle based data equipped test cars of the project partner were used. Depending on the degree of equipment, these cars were able to provide so-called ego and/or observer information. Ego information contains information about the vehicle itself, for example the own position (location information / data format: Cooperative Awareness Message (CAM)) and the current vehicle status (e.g. break down message / data format: Decentralized Environment Notification Message (DENM)) [CAM 2020 / DENM 2020]. Observer information contains information about observations made by the on-board sensors of the vehicle, outside of the vehicle itself, for example information about danger spots (e.g. people or obstacles on the road, wrong way driver / data format: DENM). Provided that the vehicles are equipped with suitable on-board equipment (precise sensor technology and fast data communication technology), a high spatial and temporal resolution of the vehicle based information is possible. Regarding KoMoD, the spatial resolution of the vehicle based data in the tunnel depended mainly on the accuracy of the positioning system of the vehicles themselves (ego information) and on the position calculation for the observed events (observer information) based on this. The temporal resolution depended on the measurement, detection or observation time as well as on the transmission time. Positioning data (data format: CAM) was sent periodically, while event information (data format; DENM) was sent event-related.

3.3 DATA CONCENTRATOR

In order to generate high-quality traffic information based on both collective and infrastructure based data as well as on individual and vehicle based information, ave has developed, planned and implemented the so-called data concentrator. The developed and implemented algorithm was able to deal with the specific characteristics of the individual data sources and to merge the different traffic data. This is a central process because the data of the different sources could differ significantly, for example in spatial and temporal resolution.

The infrastructure based collective measurement technology was able to record every single vehicle that drove through the tunnel. This enabled the generation of section-related and local traffic data as well as special alarm information. For measurement-technology reasons the section related traffic data was averaged over time (travel time) and distance (section length). The local traffic data was only averaged over time (one minute). The provided alarm messages were event related with a spatial accuracy corresponding to the section length (about 200m) and accuracy over time depending on the current travel speed (speed limit = 80km/h).

Vehicle based, individual data and information was only available for equipped vehicles of the project partners. These had a defined spatial resolution of 10m and resolution over time of 1s.

Within the data concentrator all sources were equally weighted. There was no weighting due to e.g. reliability or currentness of data. Since serious incidents (fortunately) occur very rarely, it was not possible to collect a sufficient database. During the project, no serious incidents occurred in the tunnel within normal traffic flow. Therefore serious incidents were simulated in special test scenarios while the tunnel was closed for normal traffic.

All available vehicle and infrastructure based traffic data was collected and processed by the data concentrator. After a plausibility-check of the data the current traffic situation for the Rheinalleetunnel was generated. Every five seconds a new current traffic situation was available for each of the three tunnel sections. In case of abnormalities between the current traffic flow and the driving behavior of individual vehicles alerts were generated (e.g. broken down or very slow vehicle). Also detected traffic jam situation in the tunnel led to alerts. All alerts were automatically given as traffic information from the data concentrator to the VTLZ. Accuracy and importance of the traffic information provided depended directly on the traffic data used to generate the information.

Based on the given traffic information, the VTLZ, as the authority in charge, had to decide if and what kind of measures should be taken. For this purpose, an operating and visualization interface was developed and provided by ave. The confirmed traffic information as well as the chosen measures were given back to the data concentrator and to the MDM. The data concentrator converted the traffic information into the right data format (data format: DENM). Finally converted traffic information was given to the equipped vehicles via RSU and cellular communication. Via the MDM the traffic information and the current state of the tunnel (e.g. open, closed) were available for value-added services. Last but not least the VTLZ carried out the chosen measures into the corresponding tunnel systems (e.g. warning lights, special speed limits) to inform all kind of tunnel/road users, independent of the equipment degree of the vehicles.

4. RESULTS

During the tests (laboratory and field tests) it could be shown that the data communication from the vehicles via the data concentrator into the VTLZ and back works properly and reliable. The same applied to the data communication from the infrastructure based measuring system via the data concentrator to the VTLZ and from there further into the vehicles. For both chains, only low latency times were observed, independent of the selected air interface (cellular radio or RSU).

Furthermore it could be shown that a high added value can be achieved by coupling traffic data collected by the infrastructure and the vehicles, the generation of high-quality traffic information in the data concentrator and the data exchange between vehicles and the infrastructure. The tests clearly showed that the generated high-quality traffic information can provide additional safety-critical information for both the conventional driver and the automated driving functions. Thereby traffic flow can be made safer, traffic quality can be increased, and traffic efficiency can be optimized.

5. CONCOLUSION AND RECOMMENDATIONS

New and additional vehicle based traffic data are increasingly available. This development is strongly driven by the automotive industry as well as by aftermarket suppliers. Often, data collected by the vehicle is linked to the development of new types of automated driving functions. The data collected by the vehicle can also represent an additional added value for the classic ITS world. At the same time, the data of the ITS world, which is often collected infrastructure based, can also be a safety-critical added value for conventional drivers and the automated driving functions of automatic or at least connected vehicles. Both are particularly important in safety-critical areas such as road tunnels. However, at present very little vehicle based data is available. For further tests and detailed analysis a broader data basis is necessary.

Standardization process regarding data formats has been initiated, but different approaches are competing at least worldwide. Moreover, there is no favored approach for the vehicle infrastructure communication yet.

Further research and standardization work is necessary. There is also a need to clarify who owns the data generated by the vehicles and whether or in what detail they are available for ITS purposes.

In general, the combination of vehicle and infrastructure based data for incident detection in the traffic flow is a promising approach that should definitely be pursued further.

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