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Impact Assessment and User Acceptance of Cooperative ITS for Trucks

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Abstract

The CITRUS ("Cooperative ITS for Trucks") project's main focus was the development of a mobile companion app for truck drivers which allows for enhanced road safety and improved vehicle and logistics efficiency. More than 400 professional drivers were involved in the deployment of the Truckmeister app. To evaluate the impact of the application, we conducted a field experiment with 120 drivers during a period of two months. The warning services were analysed in a quantitative manner. In most cases the data analysis demonstrated no significant decrease of driving speeds in response to the pictograms or messages shown. However, based on the acceptance and acceptability questionnaires we clearly witnessed enhanced alertness of the drivers for the warnings delivered inside the cockpit. The highest degree of 'acceptance' was noticed for the truck-aware traffic signal service, which furthermore demonstrated a clear positive impact on vehicle emissions.

Keywords:

C-ITS, Warning services, GLOSA

1. Introduction

CITRUS stands for "Cooperative ITS for Trucks". The project's main focus was the development of a mobile companion app for truck drivers which allows for enhanced road safety and improved vehicle and logistics efficiency. As such CITRUS targeted six different use cases, to be piloted in Flanders:

- Traffic jam ahead warning
- Stationary vehicle ahead warning
- (Mobile) Road works warning
- Truck-aware traffic signal regulation and traffic signal priority for special vehicles
- Real-time logistics-specific traffic information
- Intelligent dispatching

The use cases were enabled by the cooperation of the different partners in the project. This was done by the deployment of a C-ITS architecture and the rollout of key underlying technology. Logistics drivers were equipped with the solution(s) to test it in real-live traffic situation. Part of the project a monitoring and evaluation study was realised, building on the data gathered while testing the services whereas dedicated surveys realised in parallel enabled a qualitative impact analysis.

2. Technology and architecture deployed for the C-ITS setup

2.1 Architectural overview

CITRUS uses a cellular C-ITS architecture. It is linked and is compliant with C-ITS as used in different projects. The scheme in Figure 1 gives an overview of the architecture.

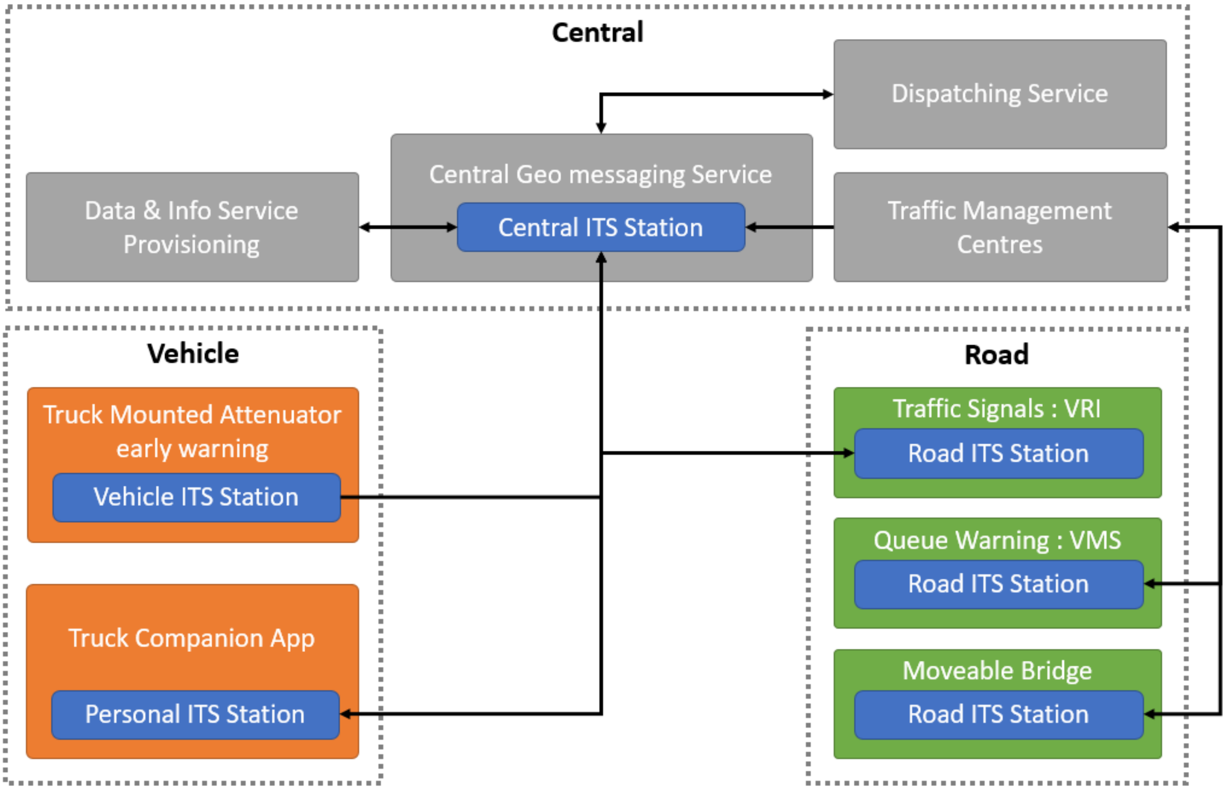

Figure 1: Overview of the CITRUS architecture.

The CITRUS architecture can be split into central platform components, components in the vehicle, and components alongside the road. The terminology of ITS stations is used for these components:

- The Central ITS Station is the component hosted on a server that connects other C-ITS stations.
- The Road ITS Stations are installed on physical assets alongside the road. In CITRUS, we use traffic signals, variable message signs, and moveable bridges as road ITS stations.
- The Vehicle ITS Station is used for built-in systems. The used truck-mounted attenuator is equipped with dedicated technology that we call Vehicle ITS station (OBU).
- The handheld devices for truck drivers as well as the smartphone application used for bus drivers and emergency vehicle drivers can be taken out of the vehicle. They are called Personal ITS Stations.

The Central ITS Station is further connected with other centrally-hosted systems. Data and information is provided by other central platforms like the Be-Mobile floating car data system and traffic event information services. The roadside systems are linked via the platforms of the traffic management centres. The dispatching service is hosted on a central server that can be reached using a web application by the Colruyt dispatchers.

The communication between the different ITS stations is done using secured point-to-point connections. The communication between the Central ITS Station and the vehicles uses cellular communication. The communication between the Road ITS Station and the Central ITS Station uses fixed line communications.

The functional protocols for all the interfaces are based on existing ITS standards. For traffic signals, the ETSI C-ITS standards are used with MAPEM for the geo-location data, SPATEM for the signal phase and timing information, SRM and SSM for the interaction with priority vehicles. Data coming from vehicles also uses CAM when communicated back to the central system.

DATEX II was used for data exchange of some interactions with the traffic management centre.

Dedicated protocols were used to connect some legacy systems, e.g., with moveable bridges, with truck-mounted attenuators, and with traffic detectors in the vicinity of traffic signals.

The Central ITS Station also logs monitored data of all different components. This data was used in the monitoring and evaluation process.

2.2 Human-Machine interface (HMI)

A lot of attention was put on the HMI of the application. Based on workshops with the involved drivers (Colruyt), a series of main principles were identified. The application should prioritise safety above all, it should not increase the workload of the driver while driving, and the information should be displayed in a clear and unambiguous way (CITRUS, 2017).

These principles lead to an HMI design where an alert-invoking event is displayed 3 km upstream by blinking triangle-shaped warning road signs. The blinking signs have different symbols for the different use cases involved. By blinking the road signs on the display, the attention of the driver is gently drawn. In the course of approaching the alert-invoking event, the saliency of the display is reduced by stopping the blinking at a distance of 750 meters. At a distance of 250 meters, the display is cleared as the driver should already have started anticipating the alert and any signal displayed would only lead to distraction. As the design of the HMI is developed in order not to distract the driver, the design principles were inquired by means of questionnaires.

The HMI of the green- and red-time information was designed as follows: when a vehicle arrives at the traffic lights along the N203a (ring road around Halle), the remaining countdown of green or red time is visualised by means of a regressing green or red circle circumventing a pre-sorting direction arrow, one arrow for each pre-sorting lane. One full circle complies with a complete green time cycle or red time cycle, respectively. The rate of regression depends on the traffic light cycle duration at hand.
The results of how the HMI looks to drivers is shown in Figure 2.

Figure 2: Overview of the various types of messages shown in the app (HMI).

An example of the use case for congestion tail warnings is shown in Figure 3.

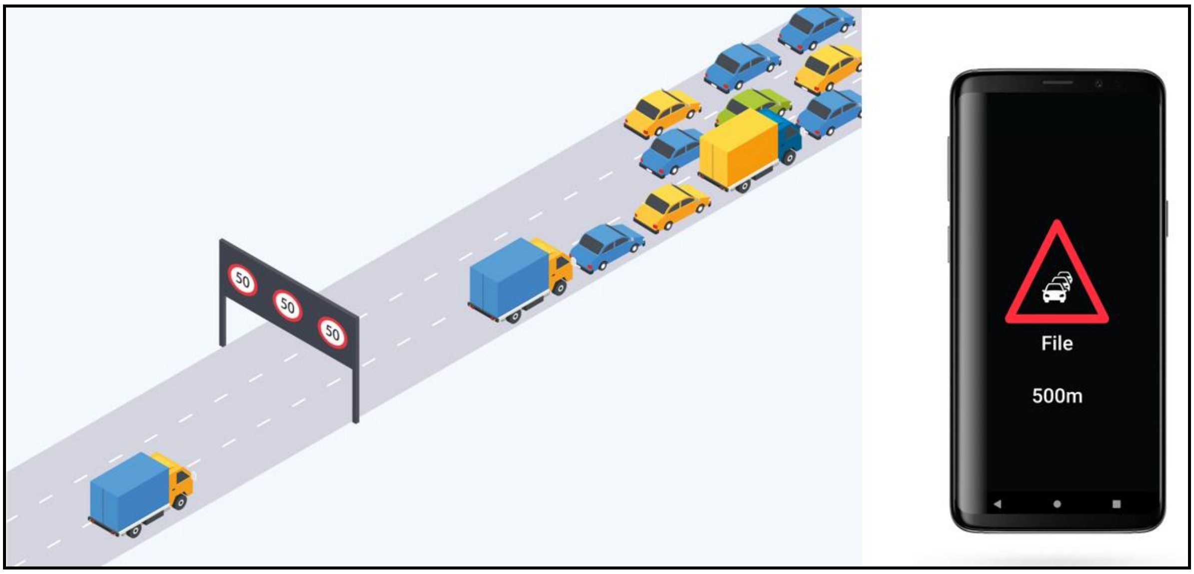

Figure 3: CITRUS as a use case for congestion tail warnings.

2.3 An integrated solution

Belgium is the gateway to Europe and therefore, heavy loads of logistic transport pass the Belgian territory. A huge number of trucks are driving on Belgian soil, especially on Belgian motorways. In this country, trucks are responsible for more than 20% of the total CO_2 emissions caused by road traffic (TREMOVE, 2010). In 10% of all fatal accidents on Belgian motorways, an approaching vehicle failed to brake in time and crashed into a traffic jam tail. In 70% of those cases the approaching vehicle is a (light) truck. Although road works on the motorways are typically well-signalled, they are still responsible for 13% of all fatalities on Belgian motorways (VIAS, 2015).

Considering these dramatic numbers, use cases were defined to mitigate or clear these issues. They are not only related to safety, but also to emissions, and congestion. The defined use cases hence adhere to reduce these.

The first experimental rollout of the companion app involved only safety-related alerts. All these alerts are aimed at improving safety, and therefore, they are referred to as the "warning service". The defined use-cases encompassed:

- Traffic jam ahead warning
- Stationary vehicle ahead warning
- (Mobile) Road works warning (RWW)

This was amended with the following warnings:

- Obstacle ahead warning
- Incident/accident ahead warning
- Danger of skidding warning

Two other services, i.e. real-time logistics-specific traffic information and intelligent dispatching were also rolled out during the first stage, but for these there was no experimental setup designed.

During the second experimental rollout of the companion app we included the following service:

- Truck-aware traffic signal regulation

The expected effect of the warnings was that the driver was alerted and attentive to the upcoming potential danger. This would reduce the number of accidents by trucks due to a lack of attention.

In the second stage, drivers received information on the green and red times of the upstream traffic lights along their route. We refer to this service as the 'time to green/time to red service' (TTG/TTR). Drivers passed the traffic lights more smoothly thanks to the timing information. The effectiveness of the service was assessed by survey and experimental methods. The attentiveness and speed of the driver were the main measures of interest. Attention can be defined as the selection of sensory input and information processing, in and to the brain. It is very difficult to measure the information streams that go through the mind of the truck driver. Therefore, this question is covered by survey methods following the user experience. Another effect of the warning service is that drivers might reduce the speed of their trucks in order to anticipate the upcoming danger. Speed was measured by means of GPS traces in a time window framing the displayed alert some seconds before and after the received warning. In the first experimental period, we investigated whether the truck drivers were slowing down as a result of the displayed alert.

In the second experimental rollout of the companion app, the time to green/time to red service was assessed. We evaluated this use case by comparing the speed distribution of traffic light passages for truck drivers driving with the time to green/time to red service against truck drivers who were not equipped with this service.

3. Impact assessment

3.1 Experimental setup

In order to assess the speed of the drivers, we introduced an experimental setup in which driving behaviour was compared in time frames when the app is active against time frames when the app is not active. In this experimental setup we dealt with confounding variables. Drivers differ from each other and can be more influenceable or obedient to traffic regulations than others, or even less. Some weeks traffic loads are heavier than other weeks. These are confounding variables if they are not equally spread among the conditions. We dealt with these confounding variables by spreading the active time of the services and the baseline over the same weeks and by spreading the participants equally over both conditions. The experimental setup is depicted in Figure 4. A and B consist of two group of drivers with originally 60 drivers in each group; columns represent successive weeks.

<table>
<tr><td></td><td colspan="10">MVP-1</td></tr>
<tr><td></td><td>09/09</td><td>16/09</td><td>23/09</td><td>30/09</td><td>07/10</td><td>14/10</td><td>21/10</td><td>28/10</td><td>04/11</td><td>11/11</td></tr>
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<tr><td>Pilot (UAT)</td><td></td><td colspan="2"></td><td colspan="4">Pilot 10 drivers - MVP-2</td><td colspan="3"></td></tr>
<tr><td>Drivers group A</td><td></td><td colspan="3">A</td><td colspan="2"></td><td colspan="3">A (placebo)</td><td></td></tr>
<tr><td>Drivers group B</td><td></td><td colspan="3">B (placebo)</td><td colspan="2"></td><td colspan="3">B</td><td></td></tr>
<tr><td>Acceptance surveys</td><td colspan="4"></td><td>A</td><td colspan="4"></td><td>B</td></tr>
<tr><td>Acceptability surveys</td><td>A</td><td colspan="4"></td><td>B</td><td colspan="4"></td></tr>
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<table>
<tr><td></td><td colspan="8">MVP-2</td></tr>
<tr><td></td><td>18/11</td><td>25/11</td><td>02/12</td><td>09/12</td><td>16/12</td><td>23/12</td><td>30/12</td><td>06/01</td></tr>
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<tr><td>Acceptability surveys</td><td colspan="8"></td></tr>
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Figure 4: The quasi-experimental designs for MVP-1 and MVP-2.

The blue placebo cells in the tables indicate the baseline. In this condition, drivers were driving with equipment, but no alerts were shown while their GPS traces were tracked. The green cells indicate the active service. In the first period before the hiatus, the service of interest was the warning service. In the second period, the service of interest was the added time to green/time to red service. Note that all the alerts from MVP-1 were still displayed during this period.

3.2 Results and impact (warning services)

For the results discussion, we limited ourselves to an analysis of the Traffic Jam and Road Work Ahead warnings (CITRUS, 2020a). These demonstrated a modestly increased deceleration after the reception of the warning. However, this deceleration is of low neglectable impact. On average speed is reduced with less than 0.6 m/s thanks to the Warning Service. We can conclude from the statistical assessment of the tracelets that no improvement in road safety is expected by an overall decrease in speed after receiving the warning.

However, the main impact on road safety will probably not come from the reduction of speed, but *enhanced alertness*. According to the European Truck Accident Causation (ETAC) study (IRU, 2007), 7.4% of all truck accidents are single truck accidents (e.g., a truck hitting a tree), and 20.6% are accidents in queue. The warning service will reduce the number of these kinds of accidents. For accidents in the queue, 22.1% are caused by non-adapted speed, 12.8% of the accidents are caused by inattention and 2.3% to fatigue. For single truck accidents, 20.3% is due to non-adapted speed, 18.6% is attributed to fatigue, and 8.4 % to inattention. The warning service can have an impact on these kinds of accidents and these particular causes. In the acceptance surveys, 50% of the drivers indicated that they are more alert thanks to the Warning Service. Assuming that 50 % of the drivers would be more alert and given the indicated percentage of the accidental causes than we can expect that the warning service will reduce the number of accidents with 5.5% for trucks. According to (ERSO, 2018), each year, 58 persons in Belgium die because of a truck accident (heavy goods vehicle and lorry < 3.5ton). 5.5% means that on average 3.2 lives can be saved each year by upscaling the warning service to all trucks in Belgium. Most of the drivers also confirmed this, as is evidenced by their responses to the acceptance and acceptability questionnaires (see Figure 5).

Although the warning service did alert the drivers, it did not alert them at the expense of a distracting salient HMI. When asking the drivers if the warning service did divert their attention from traffic, the majority of the drivers did not find the HMI too obtrusive (see Figure 6).

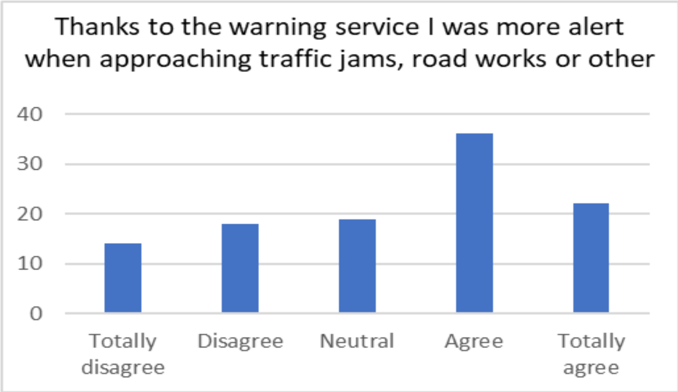

Figure 5: Attention to potential danger.

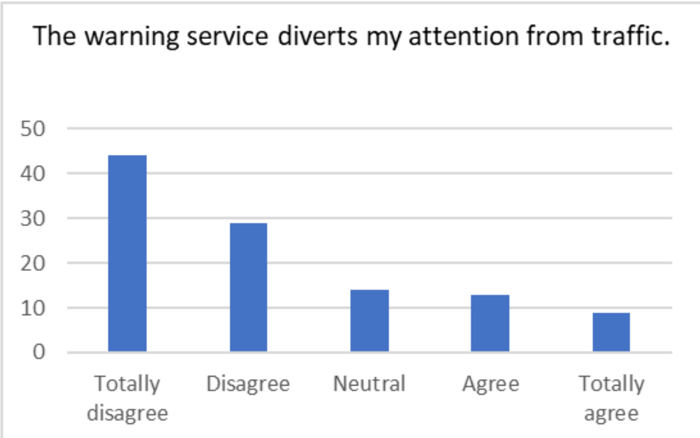

Figure 6: HMI diverting attention.

There were a considerable number of participants who indicated in the acceptance surveys that the application missed precision in signalling warning events in a timely manner. Analyses of the warning distance confirmed this timing issue, although the majority of the warnings were raised on time. Drivers indicated this timing issue especially for Traffic Jam Ahead warnings and Roadworks Ahead warnings. This is possible because these two alerts are raised much more often than any other kind of alert. When the Warning Service is perfected for timing and other technical issues, then more drivers will indicate that they are more alert thanks to the Warning Service and probably more lives can be saved.

3.3 Results and impact (Truck-aware traffic signal regulation)

During a data collecting period of more or less 6 weeks, half of the drivers were accompanied by the TTG/TTR service, and half of the drivers were not assisted by this service, thus, composing the baseline (CITRUS, 2020b). We found a tendency of higher speed and acceleration (less deceleration) when approaching the traffic lights for drivers using the service (there were 6% less samples at zero velocity for drivers guided by the service). Although the differences were subtle, the time gains were considerable. On average, the time gain was 3.6 seconds per traffic light on the main road (N203a), going to the R0 or coming from the R0. This gain was the result of the combination of two time saving features: the timing indication of the VRI cycle and the prolongation of the green time with 10 seconds when the trucks were arriving at the traffic light. This prolongation might have affected traffic flow in the perpendicular directions. When comparing speed and acceleration distributions, a significant difference was found (see also Figure 7).

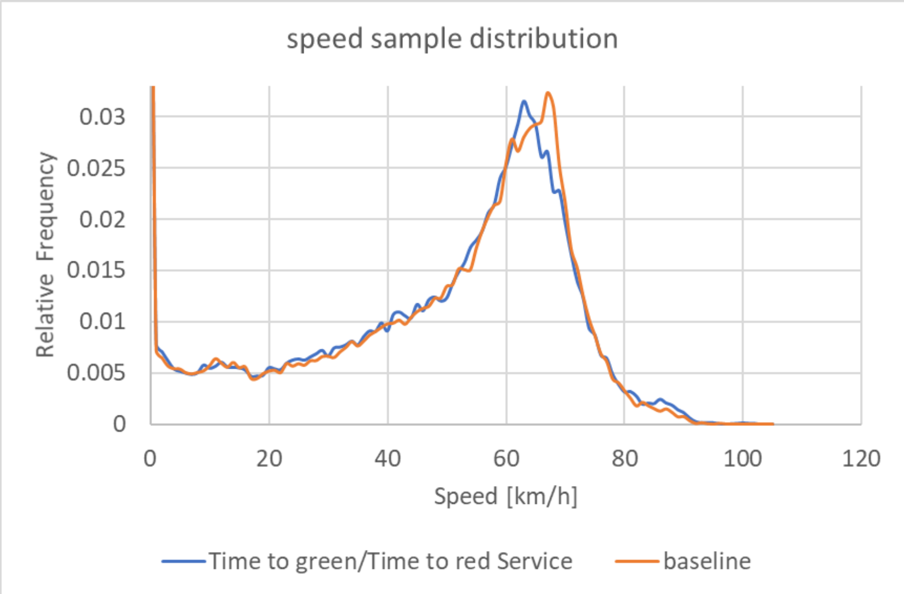

Figure 7: Empirical speed distributions for both groups.

Emissions were larger for the baseline with 37 g carbon emission reduction per traffic light by using this GLOSA service.

4. User acceptance

The acceptance and acceptability questionnaires are based on the questionnaires used in the InterCor project. In these questionnaires, the statements/items are founded on a few general research questions, such as “How do drivers value the service?”, “Do drivers feel like the service influences their behaviour” or “Do drivers believe that the services improve their overall trip quality?”. The research questions always relate to the subjective reports of the drivers which must be distinguished from the objective results conveyed during impact evaluation. The questionnaires from the InterCor project were not strictly copied when using them in the CITRUS project. They were adapted and customarily digressed to the needs and limits in the citrus project while focusing on the professional drivers hired by the Colruyt company. The positive results were confirmed in the acceptance surveys, demonstrating that most drivers were pleased with the service. Half of the drivers indicated that they believe that they received more green cycle time when driving with the companion app. Many drivers indicated that they would like to have the service permanently in their vehicle, and more than half of the drivers would recommend the service to others.

5. Conclusions

The CITRUS ("Cooperative ITS for Trucks") project's main focus was the development of a mobile companion app for truck drivers which allows for enhanced road safety and improved vehicle and logistics efficiency. The professional drivers are employed by the Colruyt company and deliver goods from the warehouse distribution centre in Halle (Belgium) to the local stores in different cities and municipalities in Belgium. More than 400 drivers were involved in the deployment of the Truckmeister app. To evaluate the impact of the application, we conducted a field experiment with 120 drivers during a period of two months. The warning services were analysed in a quantitative manner. In most cases the data analysis demonstrated no significant decrease of driving speeds in response to the pictograms or messages shown. However, based on the acceptance and acceptability questionnaires we clearly witnessed enhanced alertness of the drivers for the warnings delivered inside the cockpit. The highest degree of 'acceptance' was noticed for the truck-aware traffic signal service, which furthermore demonstrated a clear positive impact on vehicle emissions.

Acknowledgments

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