Traffic Effects of Driver Assistance Systems – The Approach within INVENT

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Summary

Within the German Research Initiative INVENT, the partial project „Verkehrliche Wirkung, Recht und Akzeptanz (VRA)“ deals with traffic effects, legal aspects, acceptance and economics of driver assistance systems. This presentation gives examples for the consulting services of VRA as well as for the early simulations of a driver assistance system. Such simulations vary in scale from basic functions over driving situations and traffic situations to traffic scenarios. Results are presented for the basic functions and driving situations for a stop-and-go extension of adaptive cruise control.

CONTENTS OF VRA

VRA is short for „Verkehrliche Wirkung, Recht und Akzeptanz“ (Traffic effects, legal aspects and acceptance) within the INVENT project „Fahrerassistenz, Aktive Sicherheit“ (Driver Assistance, Active Safety).

To guide the development in the right direction requires early results about a system’s performance concerning traffic effects, customer acceptance and economic effects. Legal aspects about traffic law, homologation and liability must be identified early, especially if the system takes over driving tasks partly or completely.

To cover these tasks the partial project VRA combines the following work packages:

- **Traffic effects**
  Advanced driver assistance systems (ADAS) are modelled and integrated in traffic simulators available at the partners. This allows to analyse traffic effects of such systems as soon as first system specifications are available. Changes in the specifications can be implemented quickly, so different system configurations can be investigated in parallel.

- **Innovation, Acceptance and Customer**
  Current and future customer requirements are analysed here. Based on system specifications from the partial projects „Staussistent“ (Congestion Assistant) and „Vorausschauende aktive Sicherheit“ (Anticipatory Active Safety) acceptance forecasts and usability are investigated. As soon as first prototypes are available, acceptance test are carried out with target groups.

- **Legal Aspects**
  The legal situation concerning driver assistance systems in INVENT is analysed. Apart from liability aspects legal requirements for information presentation and user manuals are investigated.

- **Economic Evaluation**
  The economic evaluation of the INVENT ADAS comprises individual and macroscopic economic investigations. The aim is to provide system developers with results about the potential benefit and costs for the user and society.

VRA understands its position as a service provider for the application projects Congestion Assistant and Anticipatory Active Safety. Their requirements will, therefore, govern the assessment and evaluation procedures to be developed.

VRA aims to continuously refine the results delivered to the application projects parallel to the continuing improvement of evaluation procedures. This guarantees that the results always refer to the current development state in the application projects and are produced with the latest state of evaluation procedures.

TRAFFIC EFFECTS

The work package „Traffic Effects" provides an evaluation of the ADAS in a traffic environment for the other partial projects. This evaluation delivers the system performance to the developers, accounting for various penetration rates (interaction between equipped and non-equipped vehicles). The effectiveness is determined in a variety of individual situations considering their occurrences. The effectiveness is defined by the behaviour of an equipped vehicle – in contrast to a non-equipped vehicle – in a given situation; this will lead to a change in this situation. Such changes are locally limited to the surrounding vehicles.

A multitude of individual changes in situations normally leads to traffic effects meaning that macroscopic traffic flow parameters are changed, like for example the saturation flow out of congestion. Such macroscopic changes have considerable effects on traffic as a whole, they affect all vehicles. This may lead to a totally changed traffic flow and thus changed parameters like capacity or travel times which in turn affect economic aspects for society.

VRA also delivers virtual ADAS test beds for reproducible evaluation. The system effectiveness is considered in relation to today's traffic without equipped vehicles.

Furthermore it is envisaged to enhance traffic flow simulation by means of an optimisation feature. Currently, simulation tools are used for evaluation providing results for a given system configuration in a given scenario. The optimisation feature will automatically vary parameters on the basis of an initial simulation run and continuously evaluate until given target criteria are reached.

In addition, further development will focus on the creation of a general data interface for ADAS and a traffic monitor. The following figure shows these components in their relations to the traffic flow simulation.

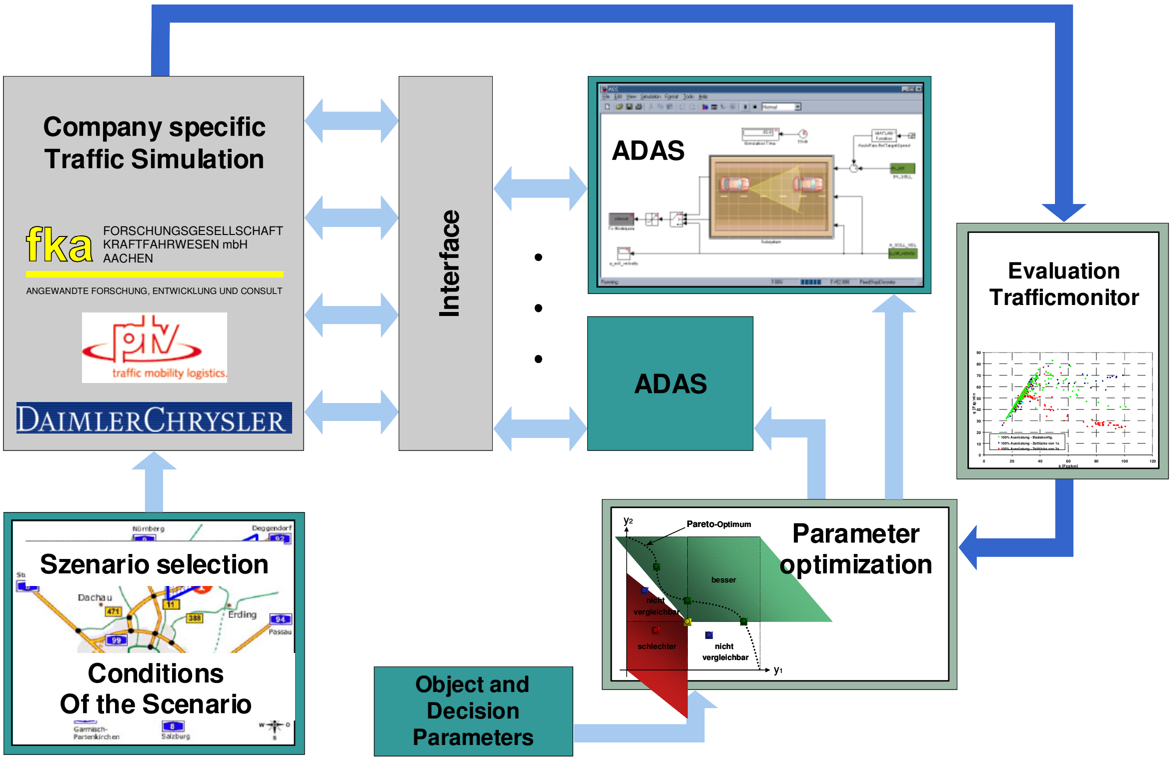


Fig. 1: Overview over new modules to enhance traffic flow simulation

Within its traffic evaluation VRA is supposed to answer questions like the following:

- How do system parameters affect fuel consumption of the own vehicle and of the others?
- What are the changes in travel time and capacity of a stretch of road depending on penetration rate (5%, 10%, 20%, 40%, ...)?
- How do different systems affect traffic safety?
- Is the system platoon stable?
- How often does the driver have to intervene? In which situations does this happen?
- In what way have the sensors to be arranged in order to optimise detection quality?

A first catalogue of questions about traffic evaluation was compiled at the start of project together with the partners from Congestion Assistant.

CURRENT RESULTS

The following presents first results worked out in the first year in close co-operation with Congestion Assistant. They comprise consulting work about congestion as such and a first ad-hoc evaluation of a controller specified by Congestion Assistant.

MACROSCOPICS OF CONGESTION

This title refers to global parameters of congestion. The questions to be answered here comprise the definition of congestion on the one hand and its consequences on the other. To this end a literature study was compiled.

When gathering literature it became obvious that only very few studies have been carried out and even less are available; interestingly, there are no official data published. The following is based on two recent investigations /1/, /2/.

Already, the definitions of congestion use different parameters and values. In /2/, „daily congestion“ is defined for a motorway section in these conditions

- average speed below 20 km/h
- average daily traffic above 80.000 vehicles per day (for two lanes per direction)
- at least one hour of congestion daily.

For reasons of comparison, the manual for traffic management systems gives different data, based on measurements in short time intervals. „Congestion“ is defined in the following conditions:

- average speed below 30 km/h
- traffic density above 60 vehicles per km per lane (for two lanes per direction)

Apart from „daily congestion“, /2/ defines „increased chance of congestion“ for

- average speed below 60 km/h
- average daily traffic above 65.000 vehicles per day (for two lanes per direction)

On this basis, the results for the year 1998 are:

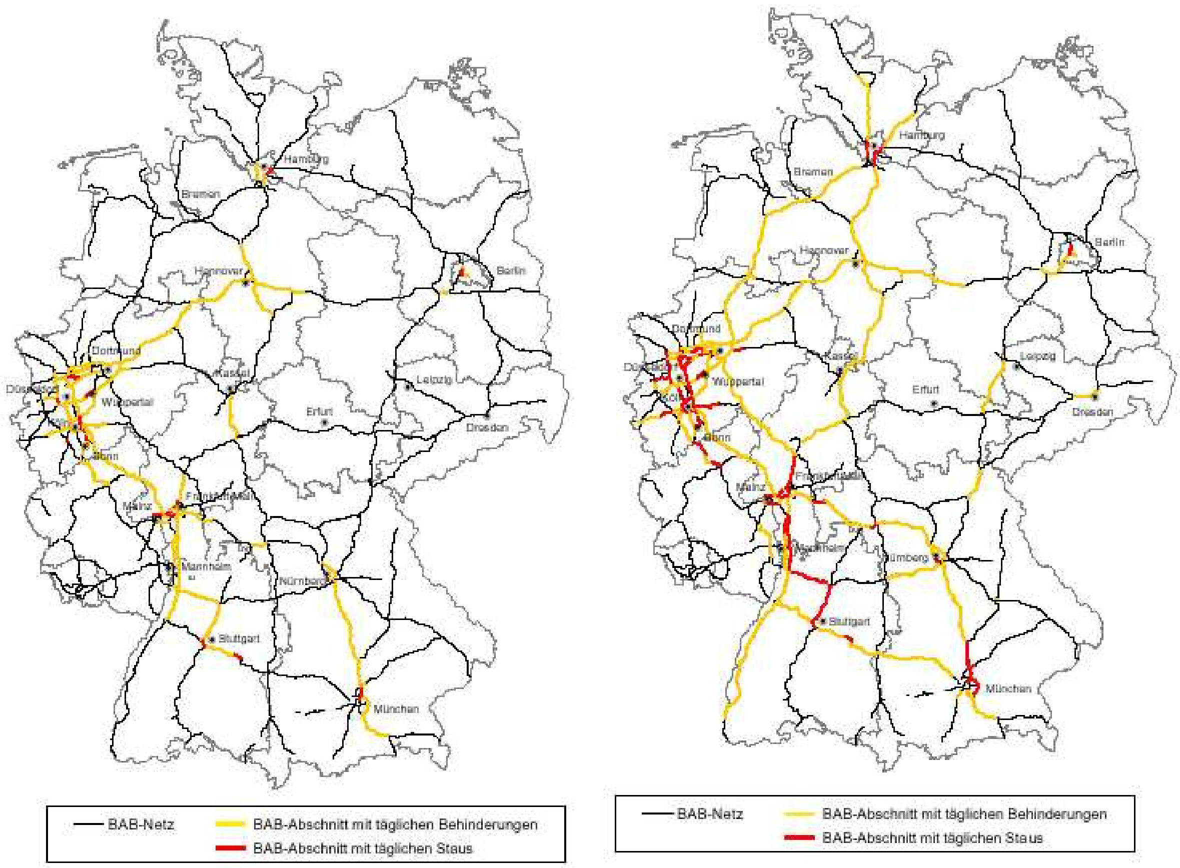
- 17% (1948.6 km) of the German motorway network (total length 11.393 km) have a high chance for congestion
- 2% (208.6 km) fall in the category „daily congestion“

For 2015, two different scenarios are distinguished. In a „trend scenario“ no political measures to control traffic development are undertaken except road pricing for trucks. In an „integration scenario“, a policy to integrate traffic systems uses supply and infrastructure oriented as well as pricing measures

Under these assumptions, the network length with daily congestion increases by 351% in the trend scenario and by 196% in the integration scenario. The following figure shows these parts of the German motorway network.

While /2/ refers to relevant network lengths, /1/ covers the user's side in terms of time loss. The motorway network, representing 2% of the total network, carries 30% of the total traffic (in vehicle kilometres). It is stated that congestion is relevant on motorways and inner-urban streets only; it can be neglected on rural roads.

In the total network, traffic amounts to 12.700 Mio veh-hours; 1.900 Mio on motorways and 7.300 Mio in cities. Congestion in the total network accounts for 7.7% of time, on motorways 17.5% or 334 Mio veh-hours, in cities 8% or 587 veh-hours. In relation to the population of Germany of about 82 million, this yields 11 hours congestion per year per capita.



1998 **2015 (Trend scenario)**

Fig. 2: Critical motorway sections (yellow: increased chance of congestion, red: daily congestion), source: /2/

As a concluding remark, it is noted that economic evaluations use a wide range of time costs. This results in large differences for the consequences of congestion, sometimes widely published.

INVESTIGATION CONCEPT

Competent statements about traffic effects of ADAS require a systematic approach to study such systems. For this reason, an investigation concept was defined as shown schematically in the following figure.

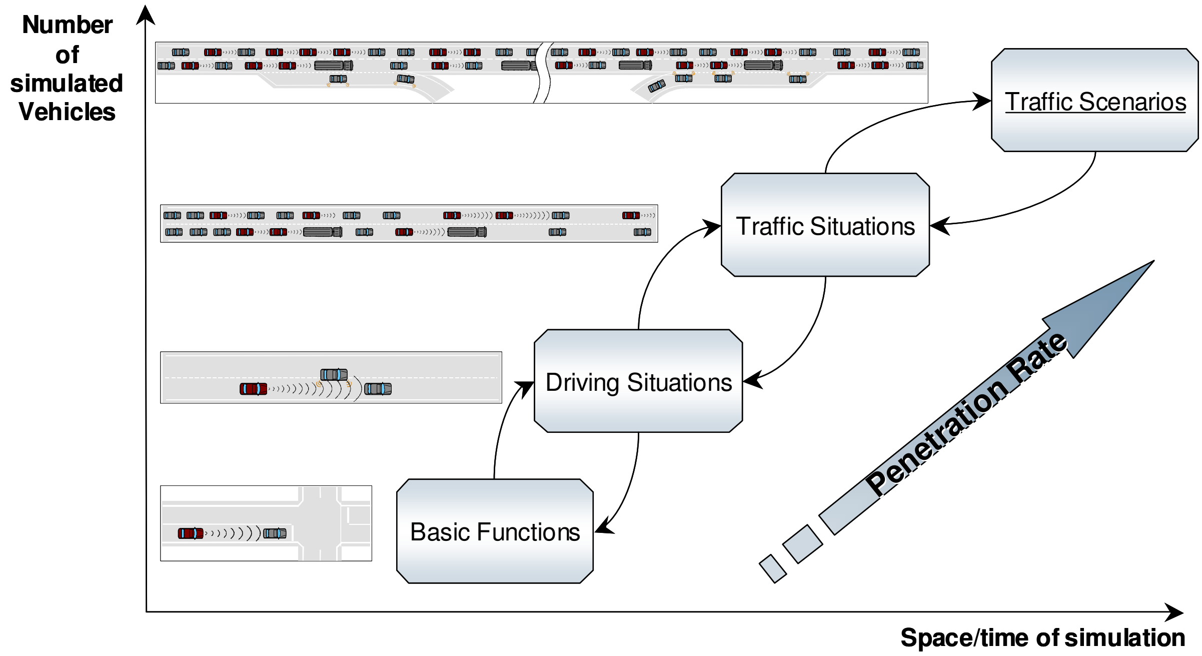


Fig. 3: Investigation concept to investigate traffic effects of ADAS

The basic idea of this concept is to start testing basic functions of the system instead of checking them in complex traffic scenarios. For the basic functions only one – equipped – vehicle is tested for a relatively short time period. This checks the system behaviour for given demand values, e.g. constant speed, constant distance.

The next step is the simulation of driving situations. They consist of a small number of vehicles with the equipped vehicle reacting to its target. The target vehicles drive according to a synthetic or realistic speed or acceleration pattern. Examples for driving situations are approaching and following manoeuvres, stop-and-go, other vehicles cutting in and platoon stability. After successful completion of driving situation simulation, the ADAS are studied in different traffic situations. They are characterised by a large number of vehicles in a limited frame in terms of time and space. This large number of vehicles allows varying the penetration rate. Examples for traffic situations are approaching a queue, driving in congested traffic, leaving a queue, reactions to disturbances, density waves or synchronised traffic flow.

The last stage of the investigation programme is the simulation of traffic scenarios, complex scenarios in a large time and space frame. Within VRA several complex scenarios are available derived from measurements in reality: motorway traffic around a bottleneck, motorway traffic with a large amount of trucks and overtaking trucks, city traffic with high volumes and junctions and others.

The concept presented here is an iterative process. It allows to evaluate ADAS at an early stage, accompany their development process and thus constantly provide input for developers.

RESULTS OF THE AD-HOC EVALUATION

The following investigation shows the improvement of a controller earlier specified by Congestion Assistant. A software model of the controller was integrated in a traffic simulation tool, and the behaviour of the controller was analysed by driving situations as described above. During the simulation the vehicle with a Congestion Assistant controller follows a leading vehicle. The predefined velocity over time of the leading vehicle is derived from real measured data of a vehicle in congestion. So, in the simulation for the following vehicle a traffic congestion situation is simulated.

The next figure shows on the one hand a good following behaviour during the congestion situation. On the other hand, when both vehicles are leaving the congestion around second 400 and 550, the figure shows a weak spot of the earlier defined controller. The distance between the two cars increases nearly up to 100 m. The current time headway in this leaving situation increases up to 5 seconds. In corresponding traffic situations the measured time headway is about 1.8 seconds. Therefore we assume, that human drivers would not accept this controller behaviour. Furthermore these huge headways and distances lead to a slow disbanding of a traffic jam. So, with regard to an optimised traffic flow this controller behaviour is unacceptable also.

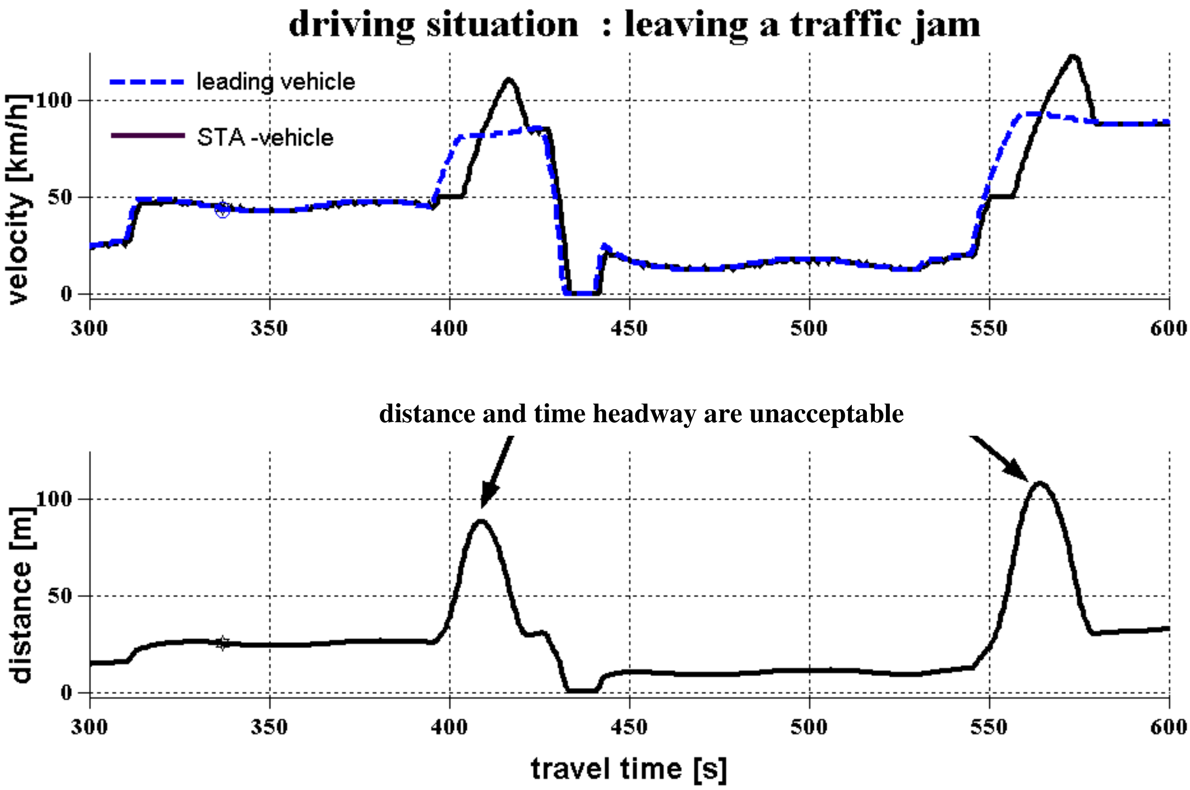


Fig. 4: Unacceptable controller behaviour during leaving a traffic jam ("STA-vehicle": vehicle equipped with Congestion Assistant controller)

The analyses of the rules and the dynamical states of the controller during simulation shows, that the reason for this undesirable behaviour results from the fact that a set of switch-off conditions are never fulfilled in dynamical controller states. Furthermore the controller decreases the acceleration, if the switch-off conditions are reached. The figure above shows this behaviour close to second 400 or 550. The velocities remain at 50 km/h. Only if the distance is larger than 65 m, the only dynamically reachable switch-off condition is fulfilled. Then, increased accelerations are allowed.

Therefore we suggested a new rule for the next version of the Congestion Assistant controller: The acceleration should not decrease to zero infinitesimally, if the switch-off conditions of the controller are reached. Then the whole set of switch-off conditions can be fulfilled, and the controller switches off before the distance reaches 65 m. The positive effect of the new rule is shown in the following figure.

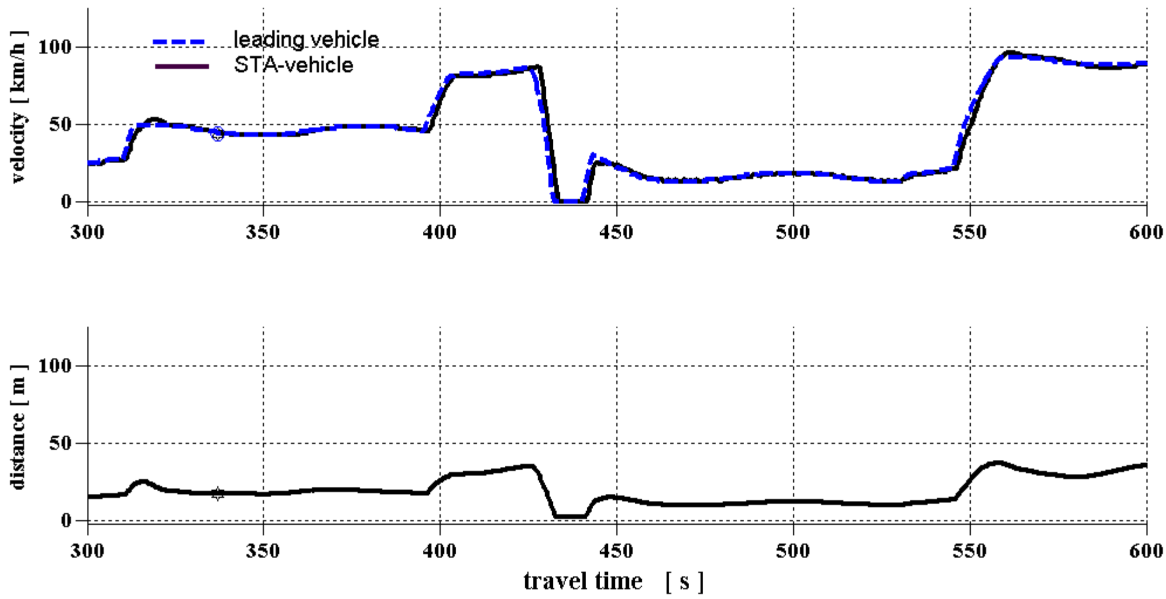


Fig. 5: Improved controller behaviour ("STA-vehicle": vehicle equipped with Congestion Assistant controller)

Concerning the last step of the ad-hoc evaluation of the Congestion Assistant, the simulation of traffic scenarios, the influences of different controller configurations and penetration rates on the traffic flow and fuel consumption have been focused. The two figures below show exemplarily some results of this investigation. The thereby simulated traffic scenario is a two-lane motorway with speed limitation (120km/h). A severe braking manoeuvre until standstill on the right lane causes the congestion.

The fundamental diagram (following figure) depicts the relation between mean velocity and traffic flow. Each dot represents a minute value aggregated out of measuring loops. The yellow line displays the reference (simulation without Congestion Assistant). Compared to this reference the "3.0s headway"-configuration (red line) has a negative effect on the course of traffic whereas the "1.8s headway" (green line) and above all the "1.0s headway"-configuration (blue line) have positive effects: not only that a headway of 1.0s increases the mean velocity in the Congestion Assistant range but also it increases the traffic flow.

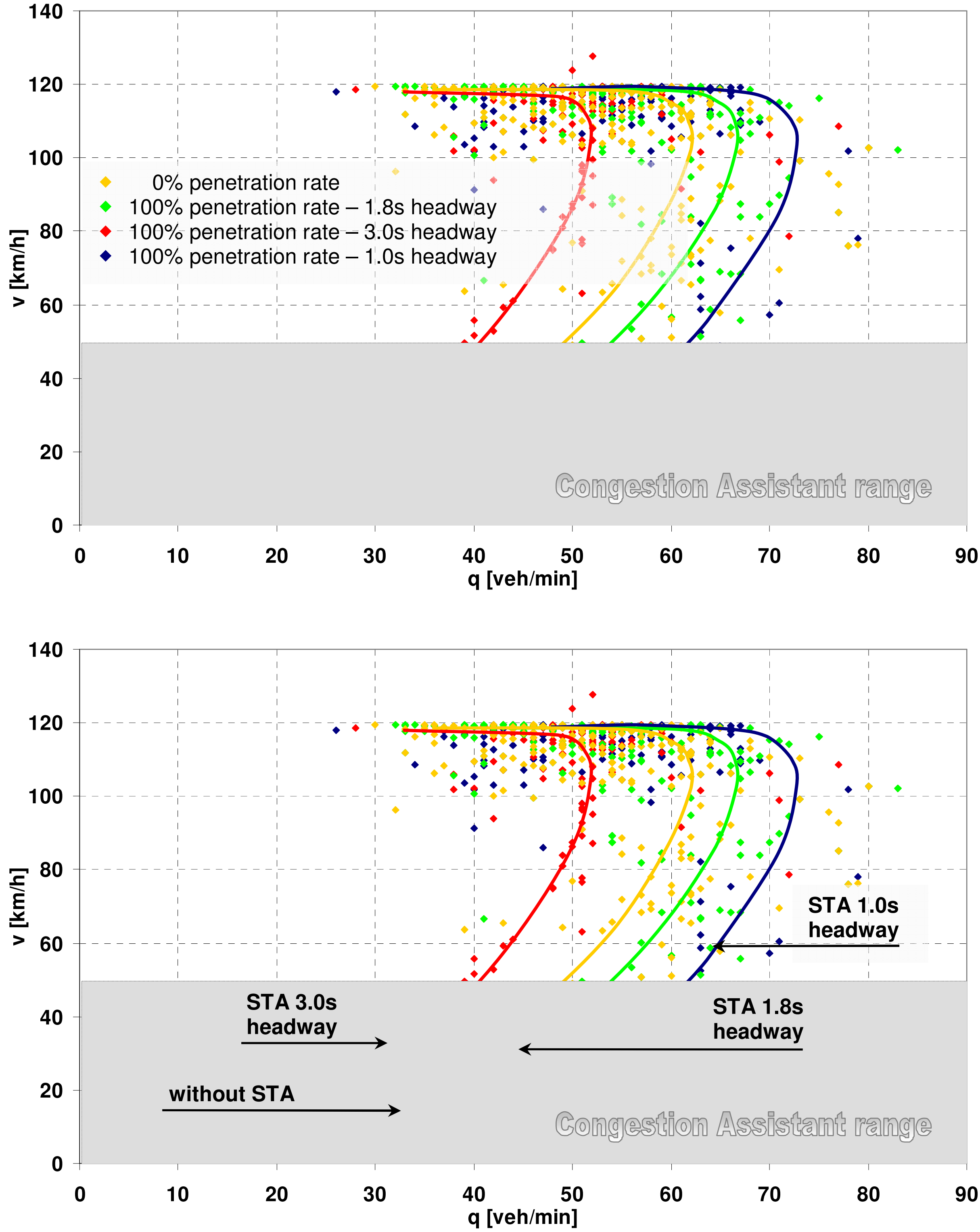


Fig. 6: Influence of different Congestion Assistant configurations on the course of traffic

The above described effects of different configurations on the course of traffic are also reflected in the fuel consumption as shown in the following diagram: compared to the reference scenario without Congestion Assistant smaller headway values (in this case 1.0s and 1.8s) show a benefit regarding the fuel consumption and the therewith associated emissions. In fact, because of the increased mean velocity in the low-speed range the vehicles (resp. the combustion engines) run in more favourable operating points. In the same way a higher headway of 3.0s leads to increased fuel consumption.

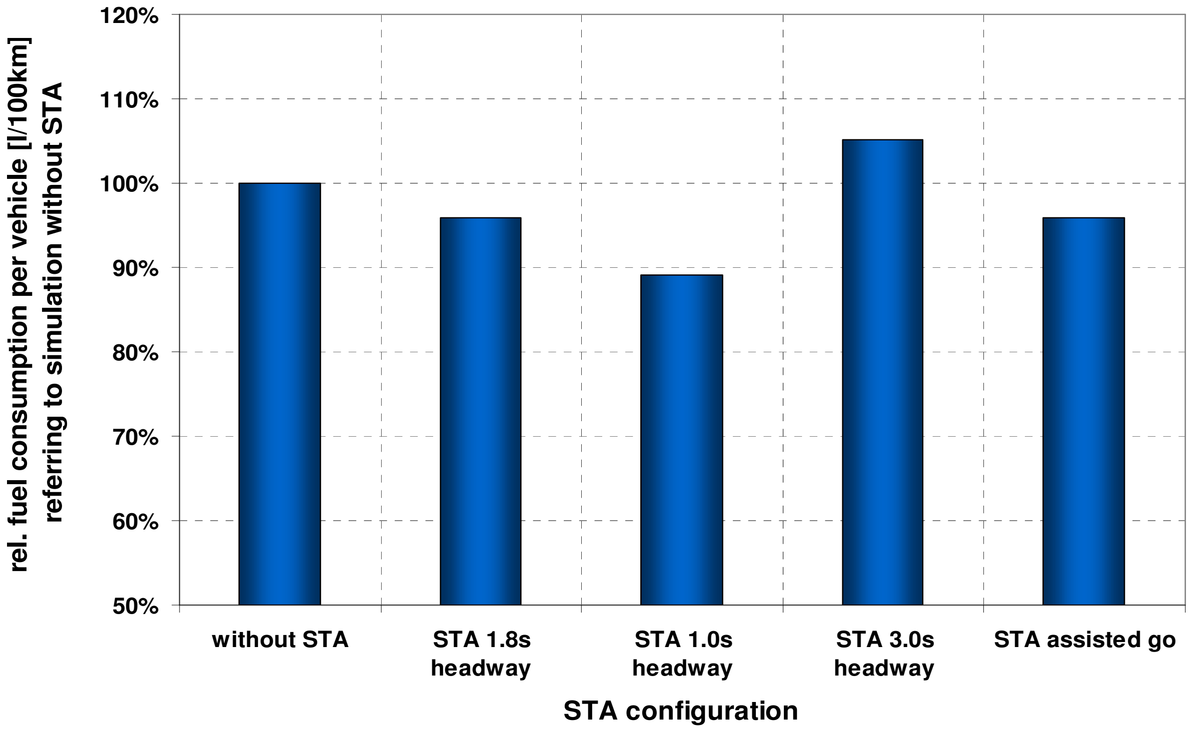


Fig. 7: Influence of different Congestion Assistant configurations on the fuel consumption

The here highlighted variations concerning the Congestion Assistant configuration are only a part of the scheduled parameter variations. For instance, besides varying the headway an assisted-go functionality has been simulated, too. Compared to the basic configuration (1.8s headway, automated go) the only difference is that starting after standstill is initiated by the driver and not by the system. The influence of this parameter on the fuel consumption is also shown on the above figure. Compared to the reference one can observe a benefit, compared to the basic configuration there is if at all only a slight difference.

CLOSING REMARKS

The work presented above shows only some examples of the work package „traffic effects". They indicate how early simulation studies deliver valuable information for the development of ADAS. The system „Congestion Assistant" is described in /4/. In the further course of work, an analysis platform and other modules will enhance the existing simulation tool for ADAS developers. In parallel to that, evaluations will be performed on a growing space and time scale so that qualified statements about the traffic efficiency are available at the end of the project.

ACKNOWLEDGEMENT

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