STRATEGY TO DETERMINE THE EFFECTS OF COOPERATIVE SYSTEMS ON TRAFFIC SAFETY AND EFFICIENCY

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ABSTRACT

Important goals of cooperative systems are to improve traffic safety and/or traffic efficiency. This paper describes an approach to determine the effects of cooperative systems on traffic safety and efficiency by combining different test environments, each with its own opportunities and limitations. Performance indicators for measuring the impact as well as evaluation guidelines for real traffic and microscopic traffic simulation scenarios are described. The paper shows that an integrated approach – as used in the German research project sim^{TD} – allows obtaining the respective information in the best suitable test environment.

INTRODUCTION

There is broad consensus in society and politics that traffic should be as safe and efficient as possible. Cooperative systems – most of which are still in development – aim to help in achieving these goals. Cooperative systems are based on communication between vehicles and/or vehicles and infrastructure (vehicle-to-X, V2X).

Several research projects deal with the determination and analysis of cooperative systems' impact on traffic. The question to be answered is how and to what extent the different applications of cooperative systems influence safety and efficiency – in a positive or negative way.

Fig. 1 shows an overview of how the effects of cooperative systems on traffic safety and efficiency may be determined.

The impacts of a cooperative system on the single user need to be analyzed, as well as the

impacts on the traffic as a whole. Thereby, possible interdependencies need to be considered.
Furthermore, the influence of the traffic environment like the prevailing traffic state, road category or equipment rate (i.e. the percentage of vehicles equipped with a cooperative system) has to be taken into account. The question of which equipment rate for the respective system is necessary to achieve a significant impact plays an especially important role for possible market introduction scenarios.

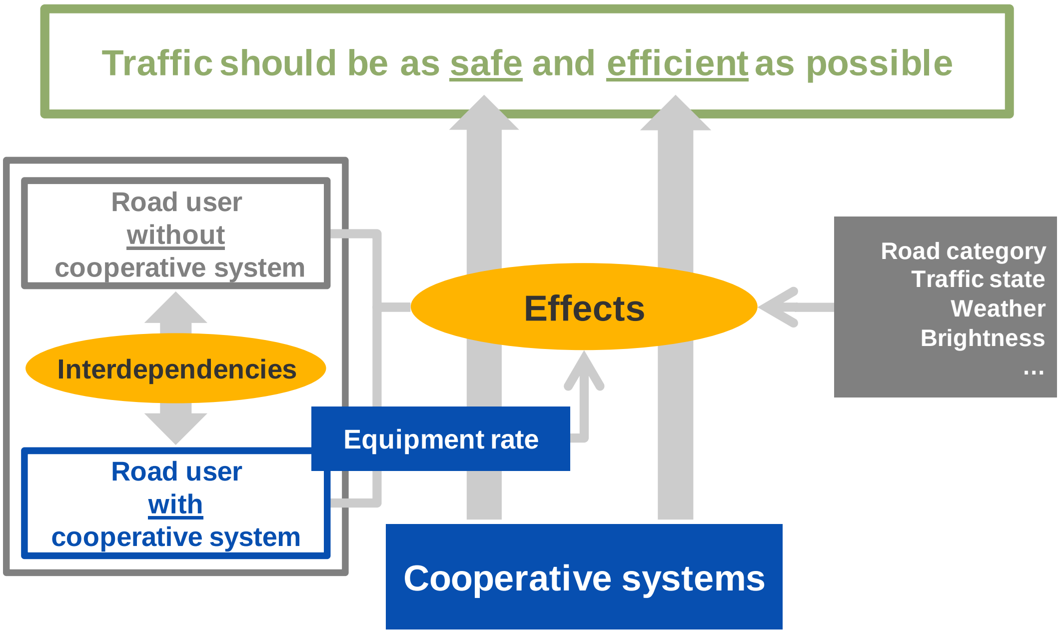

Fig. 1: Overview of cooperative systems' effects on traffic safety and efficiency

In the following sections, feasible test environments and their interdependencies are presented. Furthermore, performance indicators for measuring the impact as well as evaluation guidelines for real traffic and microscopic traffic simulation scenarios are described. The paper finishes with some conclusions and an outlook.

TEST ENVIRONMENTS

To analyze the impacts of cooperative systems on safety and efficiency, there are three plausible test environments:

1) Real traffic
2) Driving simulator
3) Traffic simulation

Each test environment has certain opportunities but also certain limitations.

REAL TRAFFIC

In *real traffic*, analysis with real vehicles and real drivers on a real network can be carried out and evaluated. This can be considered as a great advantage compared to any kind of simulation. Analyses with a fleet of test vehicles allow the impacts on drivers *with* versus drivers *without* a cooperative system to be determined. However, the estimation of impacts on the overall traffic flow is very limited, even with many test vehicles. The collection of necessary data for all other vehicles apart from the test vehicles is – at least today – often impossible (due to technical challenges and/or data privacy issues) or very expensive (e.g. airborne traffic data collection). Furthermore, systematic analyses of critical situations are only possible on roads closed for the public, and therefore the results are often not fully comprehensive.

DRIVING SIMULATOR

A *driving simulator* allows setting up specific situations in a laboratory environment. Particularly safety-sensitive situations that would be too critical to test in real traffic can be analyzed without any risk for the driver or other road users. But there are no conclusions possible for the overall traffic flow. Especially the interaction between different drivers is limited. Furthermore, driving in a driving simulator can never be fully comparable with the real situation.

TRAFFIC SIMULATION

In a *traffic simulation*, specific situations – both critical and normal – can be set up. The analysis of impacts on safety and efficiency for any equipment rate and traffic state in any kind of road network is possible. However, the driving behavior with and without the cooperative system must be known and modeled a priori. Additionally, collisions cannot be represented.

COMBINATION AND INTERACTION OF THE DIFFERENT TEST ENVIRONMENTS

The different test environments can complement one another (Fig. 2). By using the integrated approach developed within the project sim^{TD} the desired information from the best suitable test environment can be obtained (6). The driving behavior identified from real traffic or in the driving simulator can be used for calibrating the driving behavior models in the traffic simulation. In the traffic simulation different equipment rates can be analyzed.

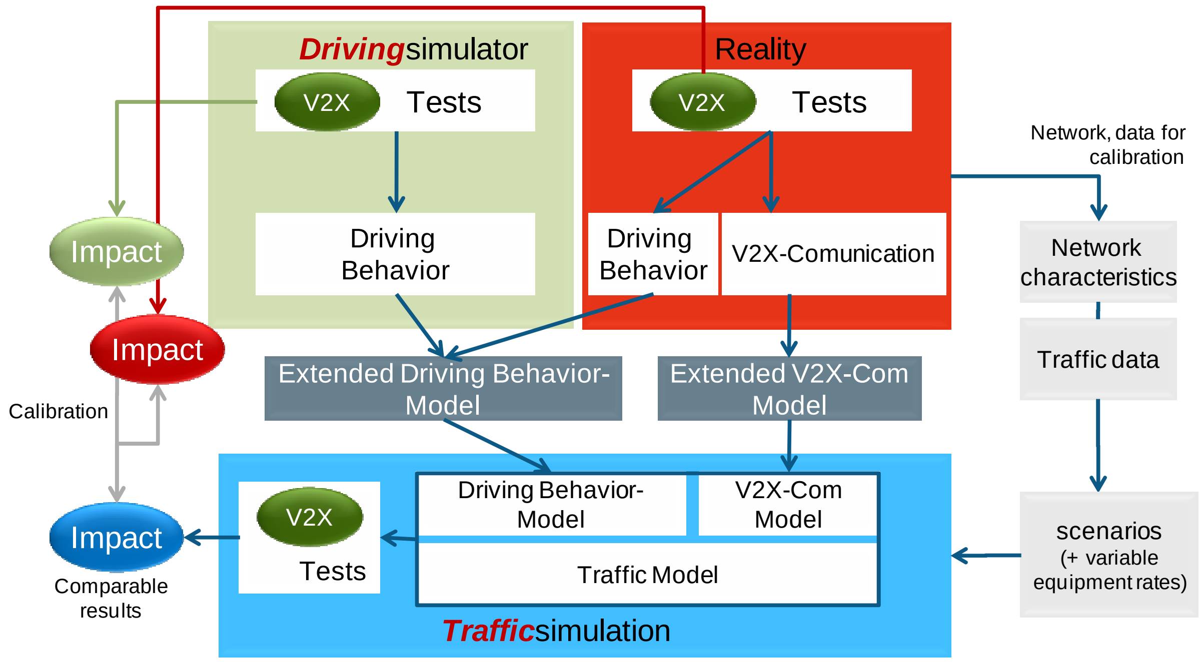

Fig. 2: Combination and interaction of different test environments (adapted from (1))

The example *congestion warning* (where an application warns the driver before reaching the end of an area of congestion) is used to demonstrate the impact analysis approach:

In *reality*: impacts concerning driver behavior and safety can be evaluated in combination with real V2X communication. Additionally, traffic environment data have to be recorded (e.g. the number of lanes, the current weather condition etc.) to enable interpretation of the measured impacts. However, to obtain statistically significant results many test drives under comparable conditions or many test drivers in the same situation need to be observed.

Here, data from a *driving simulator* is particularly valuable. The upstream congestion front can be simulated and reproduced under predefined circumstances without safety risks for the driver or other road users. Thus, it is possible to examine the driving behavior of different drivers in exactly the same situations.

The driving behavior examined in reality and/or a driving simulator can serve as the basis for an extended driving behavior model for the *traffic simulation*. Hence it is possible to ascertain the effect on traffic safety and efficiency for varying communication media and/or equipment rates (5).

PERFORMANCE INDICATORS

To quantify the impact of any system that influences traffic safety and/or efficiency, performance indicators (PI) are necessary (3). These performance indicators are either the direct or directly derived result of measurements of vehicle-generated and/or infrastructure-based data (4). The performance indicators given below are categorized as safety and efficiency indicators.

For example, the following performance indicators are suitable for traffic *safety*:

- Inter vehicle distance
- Time gap
- Time to collision
- Post encroachment time
- Speed
- Acceleration
- Number and location of lane changes
- Number of critical driving situations
- Percentage of alerted drivers
- Compliance with recommendation

For the evaluation of traffic *efficiency* the following performance indicators can be used:

- Delay time
- Travel time
- Queue length
- Number of stops
- Speed
- Capacity / saturation flow
- Lane distribution
- Capacity utilization
- Fuel consumption
- Emissions
- Total distance travelled

PIs cannot be interpreted alone, but rather in the context of the research question. The PI *speed* is a good example: a higher value can be seen as an improvement in efficiency but also as a possible deterioration in safety.

For the determination of effects, a comparison of performance indicators generated by either a driver with or without a cooperative system can be performed in various ways (see Fig. 3, (5)).

In the *driving* safety/efficiency evaluation the equipment rate is assumed as a basic constraint. All conclusions are drawn by simply comparing drivers with and without a cooperative system at a fixed equipment rate (row comparison, orange color). In contrast, in the *traffic* safety/efficiency evaluation the indicators of all the drivers having a special equipment rate (regardless of whether they are using a cooperative system or not) is compared (column comparison, green color).

Vehicles / **Equipment rate**	**0%**	**25%**	**50%**	**75%**	**100%**
Without Driver-Information/Warning	58	56	52	49	-
With Driver-Information/Warning	-	49	44	46	42
All Vehicles	58	54	48	47	42

Driving efficiency / Driving safety

Traffic efficiency / Traffic safety

Fig. 3: Difference between evaluation of driving safety and traffic safety, driving efficiency and traffic efficiency, respectively (fictitious numbers) (5)

EVALUATION IN REAL TRAFFIC

In *real traffic*, analyses of real situations with real vehicles and individuals are feasible. To evaluate the impacts of cooperative systems on traffic safety and/or efficiency, a comparison of the results of the impacts on drivers with versus those without cooperative system functionality is necessary.

For comparing these results, the drivers need to experience the same situations with the same influence of surrounding conditions. Hence, two driving designs can be applied. The first option is that all drivers drive one route twice – once with and once without a cooperative system. The second option is to set up two groups of drivers that drive the same route at the same time.

Taking the first option, the surrounding situation could change during the first and second drive. Therefore, the alignment of two groups of drivers is the most suitable option for achieving comparable results. To ensure that both groups experience the same situations, the groups have to drive the same route simultaneously. Drivers of the group *with* an active cooperative system (experimental group) receive the respective information; drivers of the other group (control group) do not receive any information from the system.

By setting specific driving routes, the groups can be managed in order to analyze the impacts of cooperative systems for special traffic environments like road category, traffic state or equipment rate. But in real traffic, the surrounding conditions may differ from the planned surrounding situation, i.e. current traffic state or weather condition. Hence, there is a need for checking the real traffic environment while both groups were driving the defined routes before evaluating the results, e.g. via infrastructure data such as detectors, in order to check the assumed and real equipment rate or traffic state.

For the evaluation of the impacts of cooperative systems on traffic safety and efficiency, various data sources are necessary. Data can either be generated by the vehicles themselves or by road side detection devices.

Vehicle generated data can include – among other things – position, distance to preceding vehicle, speed and acceleration. Data measured by road side detection usually are speed, traffic counts and occupancy. Other data sources that can support the evaluation include ANPR (Automatic Number Plate Recognition, yielding travel time, speed), video recording of specified road stretches or intersections, and airborne data collection (6).

EVALUATION IN MICROSCOPIC TRAFFIC SIMULATION

A valuable complement to a field evaluation is the application of *microscopic traffic simulation*, e.g. *VISSIM* (8) (Fig. 4).

Fig. 4: Part of the sim^{TD} road network in microscopic traffic simulation VISSIM

It allows a flexible and precise set-up of comparable basic conditions for different pre-defined scenarios. Hence, it is possible to scale the proportion of application-equipped vehicles with regard to the absolute number of vehicles within an enclosed road network, even for high traffic volumes. The basic principle of traffic simulation studies is the assumption of a given real world scenario that is modeled in a simulation environment. Those models aim to evaluate traffic related impacts by predicting the effect of newly developed systems and applications which cannot be assessed in real world observations because they are not yet available or in widespread use. A model of the generation and motion of traffic and vehicles using cooperative systems evolves by means of an appropriate statistical analysis of these behavioral studies. A useful and valid traffic simulation must take the actual traffic conditions on the relevant real road network into account. Furthermore, the control of equipped vehicles has to be influenced by detailed and appropriate models of the cooperative applications designed for real vehicles.

Thus, a simulation study modeling a real world scenario starts with the collection of all relevant data that comprise the following, among others:

- Geographical information on road networks and infrastructure installations
- Traffic measurement and demand
- Control algorithms and parameters
- Results from driving behavior evaluation and observation

Depending on the level of detail available and the capabilities of the employed simulation tool, a more or less detailed and dedicated road map can be created for the corresponding traffic simulation studies.

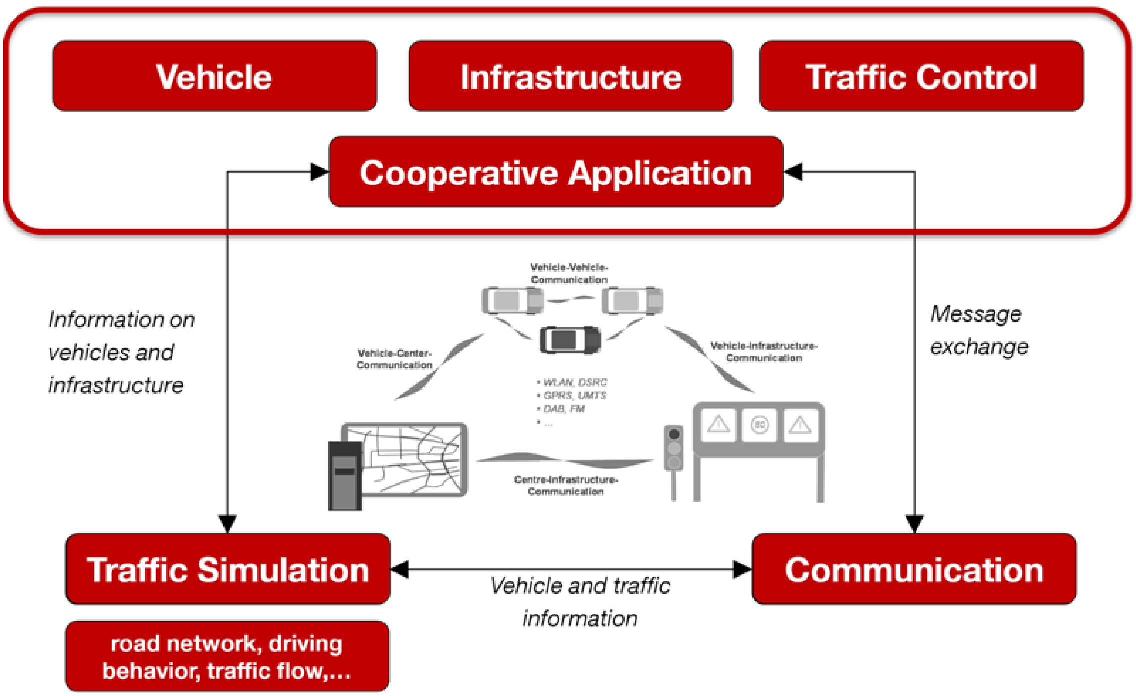

Fig. 5: Interaction between simulation model, communication model and cooperative application in traffic simulation environment (adapted from (2))

Furthermore, when aiming for valid traffic simulation for cooperative systems, different models need to be developed or refined:

- The *driving behavior model* representing the actual behavior of drivers based on evaluating real drivers; that comprises statistical distributions of describing the drivers' reactions, as well as their longitudinal and lateral movement
- A *model for the inter-vehicle and vehicle-to-infrastructure communication* establishing the basis for cooperative systems and applications
- Appropriate *mappings of traffic control functionalities* - i.e. signal or traffic control
- Adapted *mappings of the cooperative application* itself, representing the system under test

Fig. 5 depicts the interrelation between these components. The respective models for communication, cooperative applications, infrastructure and traffic are interconnected by appropriately specified interfaces forming an integrated toolset.

In order to make sure that those models represent conditions and constraints of reality, an appropriate calibration and validation process needs to be performed. That means results from the field test must be compared with the simulation results of baseline simulation studies and calibrated into a validated model that delivers acceptable variance values from reality. Details for such a process can be found in (7).

CONCLUSION AND OUTLOOK

Important goals of cooperative systems are to improve traffic safety and/or traffic efficiency. As most of the systems are still in development, the question of which equipment rate for the respective system is necessary to achieve a significant impact plays an important role for possible market introduction scenarios.

To determine the effects of cooperative systems on traffic safety and efficiency, it is reasonable to use different test environments. Each test environment has certain opportunities but also certain limitations – but they can complement one another. Using an integrated approach, as shown in this paper, allows obtaining the respective information in the best suitable test environment.

Several research projects deal with the determination and analysis of cooperative systems' impact on traffic. In the research project sim^{TD} (Sichere Intelligente Mobilität – Testfeld Deutschland, Safe and Intelligent Mobility – Test Field Germany), 27 different applications based on vehicle-to-vehicle and vehicle-to-infrastructure communication will be analyzed (6). First results from the field operational test and the traffic simulation are expected in 2012.

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