Network - wide Evaluation of Cooperative Traffic Systems using Microscopic Traffic Flow Simulation

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Abstract. The eCoMove project, which is funded by the European Commission under the 7th Framework Programme Research and Technological Development, creates a system to reduce the CO_2 emissions and fuel consumption of vehicles. The system uses the cooperative technology of V2I-Communication (vehicle to infrastructure communication). Within the different subprojects, in-vehicle and infrastructure site applications are developed. As only a limited number of vehicles are equipped with the system, network wide effects of the systems cannot be measured within the real test sides. A validation of these effects can be done using microscopic traffic flow simulation. This article introduces the concept of the simulation environment used for the validation within the ecoMove project.

Introduction

The aim of the eCoMove project is to achieve a reduction of 20% of CO_2 emissions and fuel consumption for private and transport vehicles. By providing communication between vehicles and infrastructure, drivers can receive information as to how to drive more efficiently on urban and interurban streets.

On one hand, drivers receive information on an optimal speed when they approach a traffic signal. On the other hand, infrastructure site applications use extended floating car data (eFCD) to improve the signal control.

For single vehicles it is quite easy to validate the effects. However, due to the small number of vehicles equipped with the eCoMove system within the project, it is not possible to validate a network wide effect of the system in reality. Therefore, the microscopic traffic flow simulation VISSIM [1] is used to support the development and evaluate the entire system. The simulated network is based on Munich and Helmond (Netherlands) and is calibrated with real traffic data.

To provide the infrastructure site ecoMove system with realistic traffic data, several adapters are developed to convert simulation data into messages that can be received by the eCoMove system, as in reality. This was done to make it possible to substitute the real test site by the simulation environment.

The article describes the general concept of the extended simulation environment used within the eCoMove project for development and evaluation. This is in detail the technical interfaces between the microscopic simulation and the infrastructure site eCoMove System, the modeling of the test site and the modeling of the in-vehicle systems and their calibration.

1 The eCoMove Project

The eCoMove project is funded by the European Commission under the 7th Framework Programme Research and Technological Development. Thirty two partners from ten countries are involved in the project. The partners mainly work as vehicle manufacturers, automotive suppliers, communication providers, map providers, infrastructure suppliers or at research institutions. The project started in April 2010 and will end in September 2013, with a final event in Aachen.

The project is divided up into six subprojects. In addition to project management, the sub-projects are:

- *"Core Technology Integration"*, for the development of core technologies such as the communication platform, the communication protocols, the data bases, the digital map and several traffic models,
- *"ecoSmart Driving"*, for the development of in-car applications for the support of navigation and longitudinal driving behaviour,
- *"ecoFreight & Logistics"*, for the development in-truck systems for the support of navigation and longitudinal driving behavior and central site tour planning,

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- *“ecoTraffic Management and Control“*, for the development of infrastructure site applications for central site routing and traffic light control and
- *“Validation and Evaluation“*, for impact assessment and evaluation of the whole system.

Due to the low number of equipped vehicles, it is only possible to assess the impact of single vehicles in reality. Therefore microscopic traffic flow simulation is used for a network wide impact assessment.

2 Concept of Simulation Environment

On the one hand, the microscopic traffic flow simulation should provide data for testing and parameterization of the applications developed in the subproject „ecoTraffic Management and Control“. On the other hand, it should also be used for a network wide impact assessment of the whole system.

To fulfill both requirements, a software-in-the-loop approach was chosen (see Figure 1). The software implementation for the infrastructure system is exactly the same for simulation and real test site. The simulation represents the reality and can therefore replace it.

Via adapters, the simulation provides traffic data for the eCoMove infrastructure system. The data from the virtual vehicles and infrastructure sensors is also converted into the same format as in reality. In return the traffic light control data and the driver reactions due to the recommendations given to the drivers are represented in the traffic flow simulation.

In contrast, the in-vehicle applications and the communication are not simulated but represented by models. A main reason for that is that due to computational power limits, it is not possible to connect all single eCoMove in-vehicle applications to the simulation environment. The microscopic traffic flow simulation tool VISSIM [1] is used. VISSIM uses a stochastic, time step based model. The driver-vehicle-unit is the basic unit of this model.

3 Linking Infrastructure System - Simulation Environment

In the following section, the link between the simulation and the infrastructure system of eCoMove is described. For that purpose, an overview of the architecture and the VISSIM specific communication modelling is described.

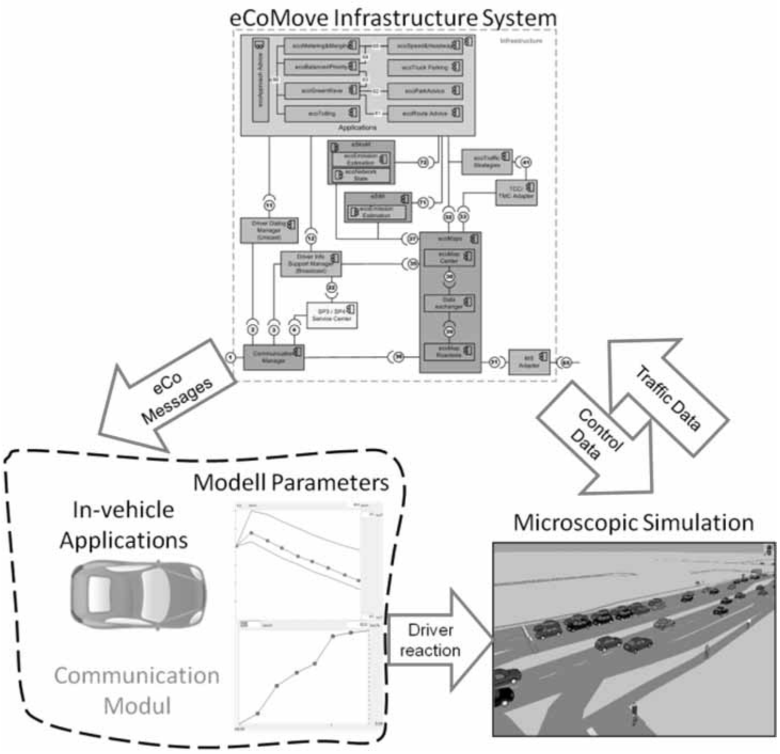

Figure 1. Concept of the eCoMove simulation environment [2].

3.1 Architecture Overview

An overview of the architecture is given in Figure 2. On the left side, the simulation environment is shown and on the right side, the infrastructure system, which can be run on a road side unit or on a central server is depicted. While the left side will be replaced by the real test site environment, the right side remains. Two example applications are selected for illustration purposes: ecoGreenWave as an example for the group of applications dealing with signal control, and ecoApproachAdvice as an example for the group of applications used for communication with the vehicle.

The system is composed of many components with loose connections. The microscopic traffic simulation, VISSIM (representative for the real test sites) is connected with the ecoMap through many interfaces. The ecoMap represents the central data repository. All static map data and dynamic data generated over time can be accessed via the ecoMap.

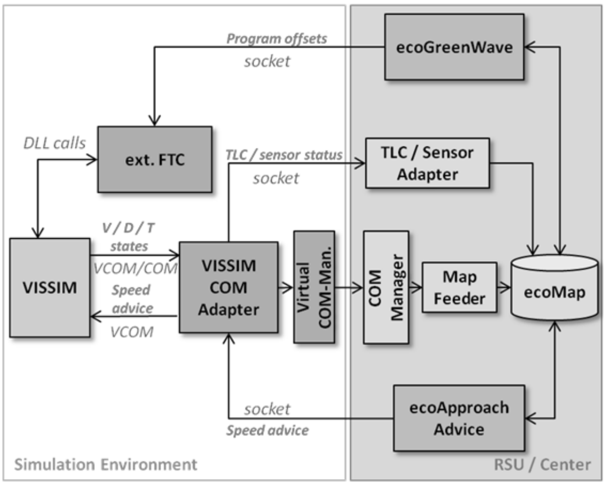

Figure 2. Architecture of the linkage simulation-infrastructure system adapted from [3].

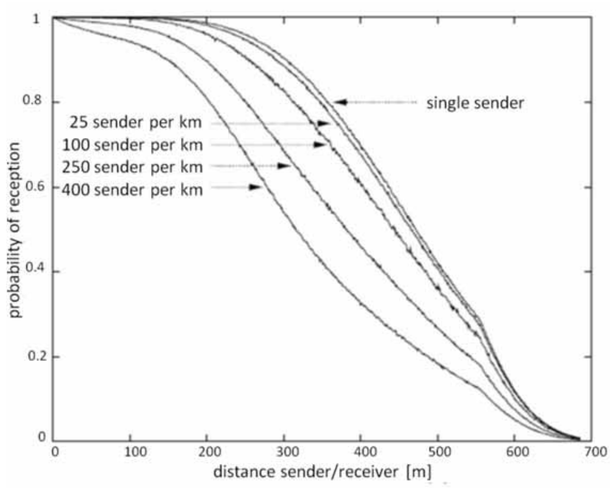

Figure 3. Reception probability depending on the distance between sender and receiver and the number of communicating vehicles per kilometer [4].

It is not implemented as a data base for data storage. It provides exchange of transient data for all applications.

The applications are implemented as OSGi (Open Services Gateway initiative) services. They communicate through a message service called ecoMessages service. If an application is interested in data from another application, it has to sign up for the corresponding for message. It gets the message as soon as it is available.

3.2 Modelling the Communication using VCOM

The communication between vehicles and vehicles or vehicles and infrastructure is modelled by the VCOM module. It is implemented as dynamic link library (dll). Given this implementation vehicle information can be requested efficiently using direct method calls. The information contains position, velocity, acceleration, safety distance, vehicle type and motion vector of the vehicles.

VCOM has a dedicated communication modelling component. The information is transmitted within a certain reception probability depending on the distance between sender and receiver and the number of communicating vehicles (see Figure 3). The reception probability is calibrated using the “Network Simulator ns-2”. Communication can be modelled using the IEEE Standard 802.11p with different reception probability distributions or using UMTS/3G. In order to access and handle vehicle information VISSIM hands over control to the specific application after each simulation step. The application receives all information on communicating vehicles via the VCOM interface.

An internal logic of the application proofs if the current information could be exchanged by sending a request to the VCOM module and it proofs if any action should be triggered. If so, the action (e.g. velocity adaption) is executed and control is handed back to VISSIM.

3.3 Implementation

In order to connect the simulation environment to the infrastructure, primarily two interfaces are needed: One to access vehicle data such as position from simulation, and one to get information on signal control and detector state. Access to vehicle data is realized using the VCOM module in the VISSIM COM Adapter. The Virtual COM Manager simply trans-forms vehicle data into the message format defined in eCoMove. Access to signal control is done in the component Traffic Light Control by calling the appropriate dll of VISSIM.

The VISSIM COM Adapter and the Traffic Light Control (TLC) interface together form the necessary framework around the simulation environment to connect the simulation to the infrastructure system. The connection itself is realized by socket connections. Therefore, communication between both systems is facilitated, even though they are based on different programming languages (the simulation environment is written in C++ and the eCoMove infrastructure system is written in Java). It is even possible to run the simulation environment on a different server than the infrastructure side.

Vehicle data and signal control data flow both to the real test sites into the ecoMap where they are accessed by the applications. The applications process the relevant data and provide the results. The resulting data flows back to the simulation environment in form of signal control adoptions (ecoGreenWave) or velocity adaption (ecoApproach Advice). The applications can be tested using the feedback channel. It has to be noted that the simulation must run in real time, meaning one simulation time step corresponds to one real second, in order to ensure that the functionality of the overall system corresponds to the runtime in the test sites.

In addition, impacts of the applications can be evaluated. Driver behaviour and emissions change due to speed advisories at intersections or due to signal control adaption can be evaluated.

4 Test Site Modelling Munich

The test site covers the main parts of northern Munich, including the Highway A99 (see Figure 4). The size was chosen to make it possible to simulate all infrastructure site applications. Therefore the routing applications were responsible for the network size.

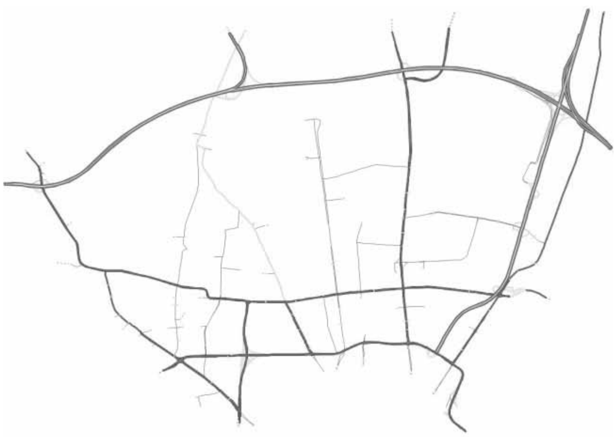

Figure 4. Network model from the macroscopic tool VISUM [5].

The network is generated from a geo database developed within the German project simTD [6]. From this database it is possible to export different networks for different simulation settings needed. Main objects of the database are the street network, sensors, traffic light control and the traffic demand including traffic volumes and routes. The traffic demand is calibrated based on the tool VISUM [5].

Both the geo database and the ecoMap are based on NAVTEQ data. Therefore the mapping is relatively easy. As the NAVTEQ data does not contain detailed enough data about the intersections, including traffic light control all intersections are modelled by hand (see Figure 5).

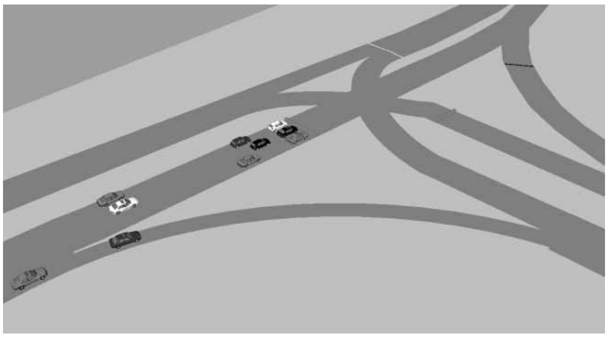

Figure 5. 3D model of a hand modelled intersection.

5 Modelling the Driver

The eCoMove system mainly influences two components of the driver behaviour: longitudinal vehicle movement and route choice.

5.1 Model for Longitudinal Vehicle Movement

For longitudinal vehicle movement, VISSIM uses a psycho-physical car following model [7][8]. The basic idea of the model is that the driver is always driving in one of the following four modes:

- *Free driving:* No influence of preceding vehicles is observable. The driver tries to reach his desired speed and to keep it.
- *Approaching:* The driver adapts his speed to the lower speed of a preceding vehicle. The driver decelerates so that the speed difference of to the preceding vehicles becomes zero when he reaches his desired safety distance.
- *Following:* The driver follows the preceding vehicle without accelerating or decelerating, trying to keep the safety distance constant. Due to imperfect throttle control and imperfect estimation the speed difference oscillates around zero.
- *Braking:* The driver decelerates if the distance falls below the desired safety distance. of the observed driver.

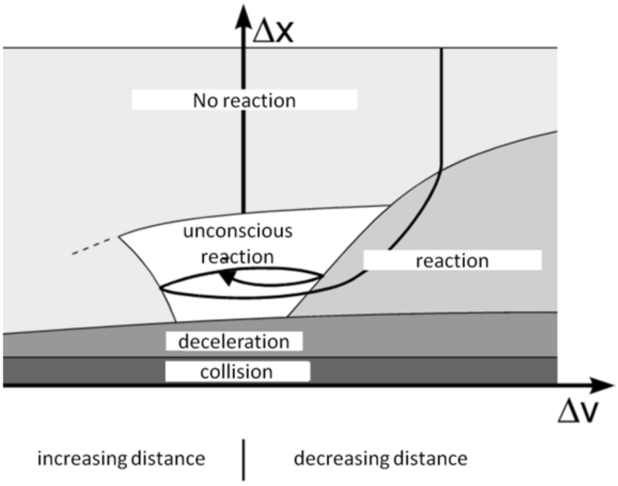

Figure 6. Car Following Model according to Wiedemann, 1974 [1].

Figure 6 shows the different modes as a function of relative speed and the distance to the preceding vehicle. In the area of no reaction the driver is in the free driving mode. As the distance is decreasing the driver changes to the approaching mode and finally to the following mode.

In the following, parameter values are listed for uninfluenced drivers. They are known from a number of measurements. For drivers influenced by the eCoMove system, no variations in these values were expected, because they only refer to surrounding traffic in direct vicinity and the eCoMove information given to the driver looks further ahead than the driver is able:

- *Look ahead distance* is the distance that a driver can see forward in order to react to other vehicles in front or beside.
- *Number of observed vehicles* affects how well vehicles can predict other driver behaviour and how to react accordingly.
- *The look back distance* defines the distance that a vehicle can see backwards in order to react to other vehicles behind.
- *Temporary lack of attention:* During this time vehicles will not react to a preceding vehicle.
- *Wiedemann model parameters:* Dependent on the chosen car following model.

Further important input parameter for the car following model are distributions of:

- *Desired velocity,*
- *Desired acceleration and*
- *Desired deceleration.*

For uninfluenced drivers, measurement values are already available. For drivers influenced by the system, parameters are determined using driver simulator studies for different use cases.

For this issue special test runs are designed to directly measure the input parameter distributions for VISSIM - desired speed, desired acceleration and desired deceleration. Figure 7 shows an approach to a traffic light with a speed advice given for the driver.

A main requirement is that the driver is able to drive his desire speed, acceleration and deceleration. This means that he is only influenced by the onboard display. He should not be influenced by other things, like other vehicles as this would falsify the measurements.

As already mentioned, the influence on the longitudinal driver behaviour by other vehicles is already recognized by the car following model from Wiedemann.

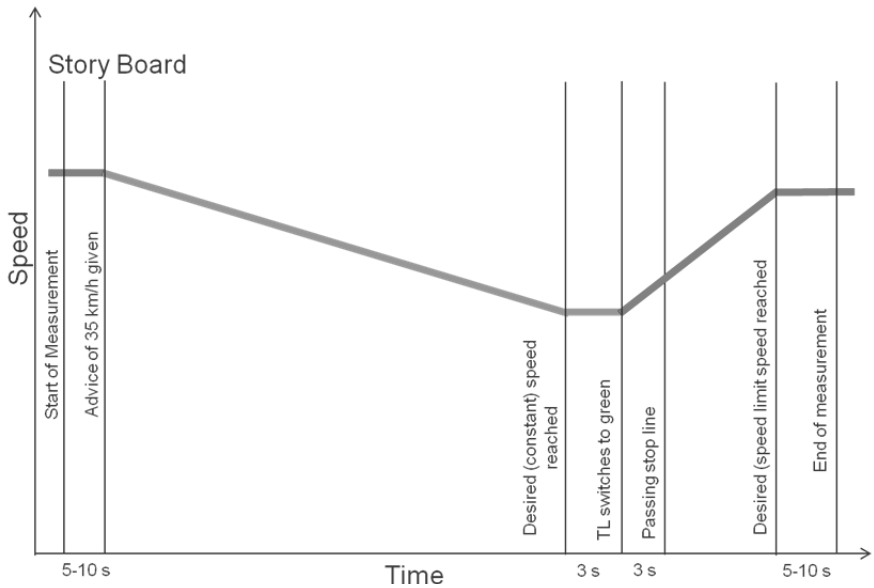

Figure 7. Story board of a traffic light approach for the calibration of VISSIM by a driving simulator study.

5.2 Route Choice

The compliance rate of drivers getting a route advice depends on many factors, such as the navigation device, the number of alternative routes, and the length and travel time of the route choices.

Therefore, a calibration of route decisions through driver simulator studies does not make sense. For drivers who are not familiar with the place, a compliance rate of hundred percent can be assumed. To determine the compliance rate of local drivers, data of the research project wiki [9] are used. In wiki, the route choice behaviour of local drivers has been investigated in the north of Munich.

6 Conclusion

The microscopic simulation environment described above is used to parameterize, test and evaluate the infrastructural applications and their combination with the in-vehicle applications on a network level. It outputs traffic efficiencies and inefficiencies within the network as a direct result.

In addition assessment of different penetration rates is possible and we can study the effects of the eCoMove system on vehicles equipped with the system separately from the effects on non-equipped vehicles.

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