# SIMCO3++: SImulation of Mobile COmmunications based on Realistic Mobility Models and Road Traffic Scenarios

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**Abstract**

The performance evaluation and simulation of mobile communication networks requires the realistic and efficient modelling of the movements of mobile stations. In this paper, the mobility model of the integrated simulation tool "SIMCO3++" (SImulation of Mobile COmmunications) for the performance evaluation and verification of short-range vehicle-beacon and inter-vehicle communication protocols is presented and validated with motor-way measurements performed by the Dutch Ministry of Transportation (Rijkswaterstaat). The results of a comparison of the motor-way measurements and the traffic scenarios simulated by SIMCO3++ are discussed. The comparison shows a very good correspondence in important aspects like following distances between vehicles, average speed of vehicles, distribution of vehicle classes over the lanes.

## 1 Introduction

New RTT applications will require more or less extensive communications to exchange relevant information between vehicles and roadside beacons (e.g. Automatic Fee Collection, Route Guidance, Parking Management, Medium Range Preinformation, Intelligent Intersection Control, Emergency Call, etc.) and between vehicles (Intelligent Cruise Control, Intelligent Maneuvering Control, Lane Access, Emergency Warning, etc.). To guarantee the functionality of the developed communication protocols and RTT applications and to optimize the parameters under various environmental conditions, computer-simulations are essential for the system design, as well as for the specification of standards (CEN / TC278) for an operational Integrated Road Transport Environment (IRTE) network [1].

The mobility model used in SIMCO3++ to simulate the movement of vehicles (private cars, trucks, busses, etc.) under various environmental conditions (multi-lane motor-ways / rural roads with section-wise speed limits, intersections, etc.) has been validated with Dutch motor-way measurements performed in 1991. The basic simulation model (vehicle movements, communication protocols, data exchange, and RTT applications) is described in Section 2. In Section 3 the road traffic characteristics, which are relevant for communications, are described. The modelling of various traffic scenarios and mobility characteristics is discussed in Section 4. In Section 5, the Dutch motor-way measurement scenarios are described. The results of the Dutch motor-way measurements and the corresponding SIMCO3++ simulation results are compared in Section 6. Finally, the conclusions from these comparison and a summary of SIMCO3++'s further extension are discussed.

## 2 SIMCO3++ Simulation Model

For the performance evaluation of communication protocols, a simulation model is required, which allows the integrated simulation of both, vehicle movements in a dynamic network and the communications between vehicles and roadside beacons and between vehicles [7]. Figure 1 shows the basic building blocks of such a simulation model and their interdependency. First, realistic vehicle dynamics, based on mobility mechanics, traffic statistics, environmental conditions and driver behaviour must be simulated. The

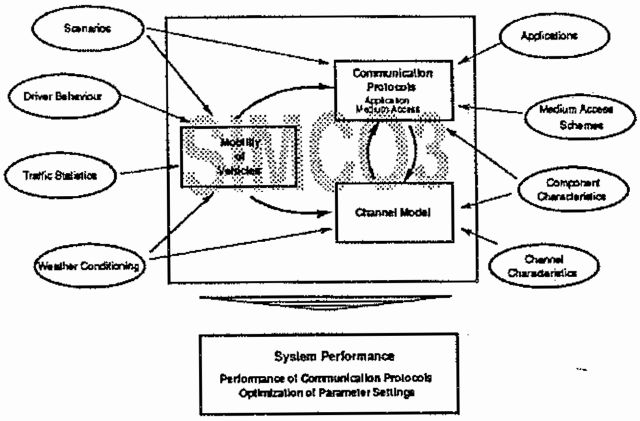


Figure 1: Simulation concept SIMCO3++

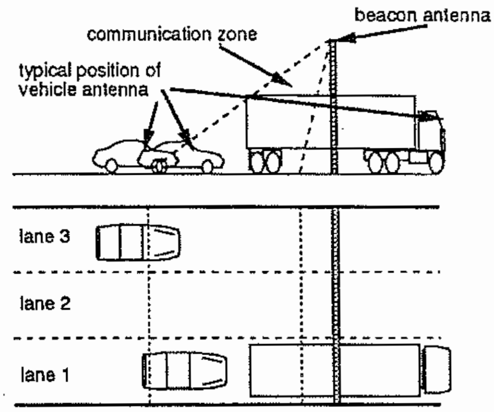


Figure 2: Vehicle-Beacon-Communication

exchange of information of current vehicle and road characteristics, conditions, fixed and dynamic traffic situation and restrictions (e.g. speed limits, traffic lights) are important for the IRTE system and require communication links to roadside infrastructure and/or between vehicles.

For these communications, which might be single- or multi-hop, specific communication protocols (medium access control, logical link control, routing strategies, etc.) are currently being developed by communication groups of the DRIVE II programme and within standardization bodies (e.g. CEN / TC278). Due to their interdependency with the vehicle movements, the environmental conditions, and the current traffic scenario, the protocol performance should be evaluated by integrated simulations of the dynamic network and the corresponding data flow. Communication relevant parameters, like channel characteristics, roadside communication infrastructure, etc. are taken into account in these simulations.

Computer-simulations based on this realistic simulation model, provide the required results for the determination of minimum requirements / optimal values of communication characteristics, and allow an accurate performance evaluation of the developed communication protocols.

# 3 Road Traffic Characteristics Relevant for Communications

The modelling of the traffic should be as accurate as necessary (concerning the effects of the mobility on the performance of the communication protocols) and as lean as possible (in order to allow efficient implementation in the simulator). Therefore it is necessary to analyze, which characteristics of the road traffic are relevant for the communications. In vehicle-beacon communications, a relatively short section of a motor-way (up to around 100 m) is relevant, whereas in vehicle-vehicle communications a longer motor-way section has to be regarded (several kilometres). The topology of the network (relative position of vehicles towards each other) is of special importance for the protocol functionality and performance for inter-vehicle communications. In the following, the specific characteristics regarding vehicle-beacon communications are discussed in more detail:

**Speed and vehicle types** Each beacon provides a characteristic communication zone, which depends on a number of parameters, such as the antenna configuration and transmission medium. As the length of the communication zone is limited in any case, the speed of the vehicles determines the available communication time of each vehicle. In addition, the vehicle type has to be taken into account. Figure 2 shows the simplified model of a communication zone (microwave): the zone gets shorter, the higher vehicle antenna is positioned. Since the typical position of the vehicle antenna depends on the vehicle types, different vehicle types have to be taken into account.

For the calculation of shadowing effects additional vehicle-type specific parameters have to be taken into account (see also figure 2): the height of the vehicle's antenna, its longitudinal position (distance from vehicle front) and the height of the vehicle in front. Furthermore, the exact knowledge of the following distances between vehicles is necessary (see below).

**Traffic Intensities and Distributions of Inter-arrival Times** Due to the characteristics of the communication of vehicle-beacon communications, it may occur, that several vehicles transmit data at the same time in the same communication zone (see figure 2). Therefore the characteristics of the free traffic flow have a strong influence on the systems performance: the traffic intensity as well as the distribution of the inter-arrival times (following distances of vehicles on a specific lane) are of importance. The higher the percentage of vehicles, that have very short inter-arrival times, the higher the probability, that the protocols have to cope with data collisions [3] [6] [5].

# 4 Modelling of Road Traffic Scenarios

The simulation tool SIMCO3++ has been designed to fulfill the simulation requirements of performance evaluation of new communication protocols. In the following section, the model approach for the simulation of various traffic scenarios is discussed in detail.

## 4.1 Simulation Scenarios

The new mobile communication protocols, currently being developed for vehicle-beacon and inter-vehicle communication systems must provide optimal functionality for traffic scenarios with different characteristics. Therefore the following classes of road traffic scenarios can be simulated by SIMCO3++: motor-ways, rural roads, intersections, road narrowing scenarios, access ramps. Up to 6 lanes and a lane-specific traffic intensity can be specified for each direction. Special road characteristic like speed limit, blocked lanes can be added. All maneuvers of vehicles, that are implemented in the mobility model (see section 4.3) are influenced by the specified road conditions.

## 4.2 Vehicle Generation

The initial generation of vehicles and their basic characteristics is one of the key problems in realistic traffic models. SIMCO3++ allows to generate (and simulate) several vehicle classes (private cars, vans, trucks, etc) with the following statistical properties: overall percentage of the class (lane specific), average speed and inter-arrival time, reaction time, set of risk factors, maximum speed, intended speed and vehicle length. These characteristics include all those parameters, that are necessary to ensure both a realistic traffic generation and a realistic behaviour of vehicles.

Whenever a new vehicle is generated, its individual intended speed, its set of risk factors, the reaction time, the vehicle length and height, etc. is assigned, using a (pseudo) random number generator according to statistical distribution determined by traffic measurements.

## 4.3 SIMCO3++ Mobility Model

The mobility model of SIMCO3++ is based on a microscopic view of the traffic. The behaviour of all vehicles depends on a set of rules and was designed to determine the reaction of a vehicle according to its local traffic environment. These rules take into account factors such as acceleration, deceleration, overtaking maneuvers, merging maneuvers, selection of the preferred lane, etc. The periodical update of the mobility scenario in small mobility time steps (several ms) ensure the continuous movement of all vehicles and creates a realistic traffic flow.

As the decisive factor for vehicles' reaction, risk factors were introduced, that are calculated before each mobility step [2]. The actual speed of surrounding vehicles and the distance between them are used to determine a risk factor for each direction. These risk factors are used to assess the actual traffic situation the vehicle has to react in. The factors are compared with a set of 'maximum risk factors': each set is specific for each vehicle and influences the vehicle's traffic behaviour. By parameterizing these maximum factors with a distribution function, different types of driver' behaviour were modelled in the mobility model. In normal situations, the calculated risk factors are smaller than the vehicle's maximum factors. Therefore the vehicle attempts to drive with its intended speed. It also tries to move to its preferred lane if it was caused to change lane by former driving activities. If the risk factors exceed the vehicle's maximum risk factors, a corresponding rule (e.g. about deceleration or overtaking) initiates the required vehicle actions.

# 5 Road Traffic Measurements on Motor-Ways

The mobility model of SIMCO3++ was validated by comparison with Dutch motor-way measurements [2] carried out as part of a project commissioned by the Transportation and Traffic Research Division of Rijkswaterstaat. Measurements were done during several months in 1991 on the A2 motor-way between Utrecht and Amsterdam, via the research facility of the Motor-way Control Signalling System (MCSS) yielding arrival instants, lane, speed and length of passing vehicles at 16 cross-sections [1] [4]. A study section of 2.9 km was chosen between cross-section A2E53.200 and A2E50.300 in the direction Amsterdam to Utrecht. This is the only section along which there are no entrances or exits. There is however, an exit about 400 m after the end of the study section. This has an influence on the measurement data, as will be discussed in the next session.

For the validation of the mobility model of SIMCO3++, different measurements were analysed. For each measurement site, the following parameters were measured per vehicle:

- lane, in which the measured vehicle was in, indicated by the lane number (1=right/2=middle/3=left lane)
- Arrival time (in hrs:min:sec) of the vehicle
- Current speed of the vehicle (in km/h)
- Length of the vehicle (in m) from which the vehicle class can be derived: e.g. 'Car': $length <= 5$ meter; 'Truck': $length > 5$ meter

To be able to compare the measurements with the simulation results, the following methods were applied:

1. The traffic statistics (average speed of vehicles, standard deviation of speed, traffic intensity, etc.) at the beginning of the study section were computed and specified as simulation input parameters for SIMCO3++ (dataset MES1). Based on these road traffic characteristics, vehicles were generated by SIMCO3++ (dataset SIM1) and simulated according to the mobility model described in section 4. Finally the traffic statistics at the end of the simulation range, corresponding to the distance between the measurement sites were computed and reported in the simulation results file (dataset SIM2) in order to compare them to the measurements (dataset MES2 holds data from the end of the study section).
2. Instead of generating the vehicles according to the measured traffic statistics, it is also possible to feed SIMCO3++ directly with the measured data (arrival time, lane, vehicle class, vehicle-length), to simulate the further behaviour of the injected traffic according to the mobility model of SIMCO3++, and finally report the simulation results (traffic statistics) at the end of the study section (second measurement site)

# 6 Comparison of the SIMCO3++ Model with Measurements

The table 1 and the figures 3, 4, 5, 6 show characteristic results of a comparison of a 3-hours measurement on the A2 with high traffic intensity and data generated by SIMCO3++ are shown. The data at the beginning of the study section (datasets MES1 and SIM1; vehicle generation using method 1 as described in the previous section) and at the end of the section (after 2.9 km; datasets MES2 and SIM2) is presented. The comparisons of the measurements and the SIMCO3++ results show:

1. Comparison at the beginning of the study section (MES1 vs. SIM1)
   The lane-specific traffic intensity, the mean parameters speed and inter-arrival time as well as the distribution of vehicle classes correspond very good: the maximal relative error between the measured data and the data generated by SIMCO3++ is around 6 % (table 1). Furthermore the distributions of inter-arrival times and speeds for the different lanes show as well a good correspondence (figures 3 and 4).

| Parameter | Lane | Beg. of Section | | End of Section | | Comparisons | | |
|---|---|---|---|---|---|---|---|---|
| | | Measur. MES1 | SIMCO SIM1 | Measur. MES2 | SIMCO SIM2 | MES1 SIM1 | MES1 SIM2 | MES2 SIM2 |
| intensity (veh/h/lane) | 1 | 1212 | 1212 | 1040 | 1298 | 1.2 % | 7.1 % | 24.8 % |
| | 2 | 1704 | 1802 | 1752 | 1634 | 5.6 % | -4.0 % | -6.7 % |
| | 3 | 1333 | 1353 | 1460 | 1456 | 1.5 % | 9.2 % | -0.4 % |
| mean speed (km/h) | 1 | 95.2 | 94.7 | 94.3 | 87.5 | -0.5 % | -8.1 % | -7.2% |
| | 2 | 109.3 | 107.6 | 109.6 | 106.8 | -1.1 % | -2.3 % | -2.6 % |
| | 3 | 118.3 | 118.0 | 118.6 | 116.4 | -0.3 % | -1.6 % | -1.9 % |
| mean inter-arr. time (sec.) | 1 | 2.66 | 2.70 | 3.24 | 2.53 | 1.5 % | -5.0 % | -21.0 % |
| | 2 | 1.98 | 1.85 | 1.93 | 2.05 | -6.6 % | 3.7 % | 6.2 % |
| | 3 | 2.59 | 2.53 | 2.36 | 2.34 | -2.3 % | -9.6 % | -0.8 % |
| car/truck distr. (%) | 1 | 77/23 | 77/23 | 71/29 | 80/20 | | | |
| | 2 | 97/3 | 97/3 | 98/2 | 96/4 | | | |
| | 3 | 100/0 | 100/0 | 100/0 | 100/0 | | | |

Table 1: Comparison of measured data and SIMCO3++ data

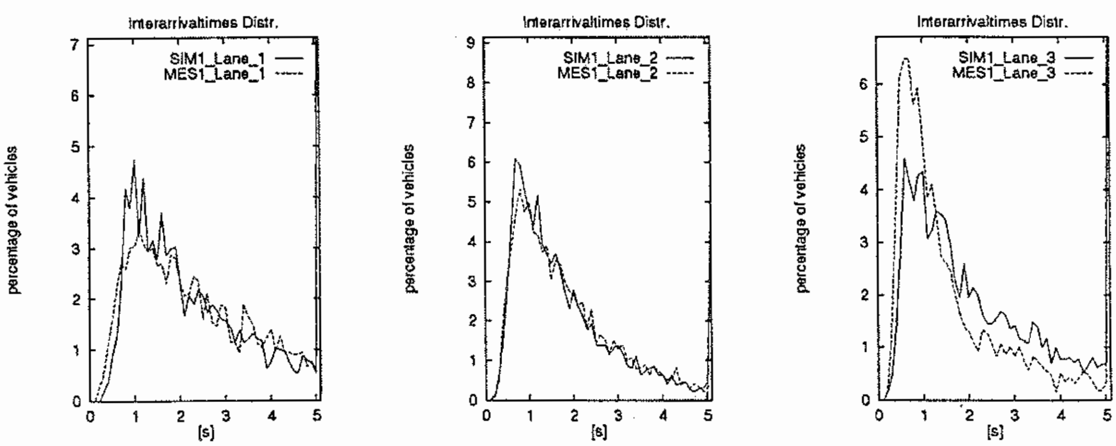


Figure 3: Inter-arrival times (MES1 vs. SIM1: right/middle/left lane)

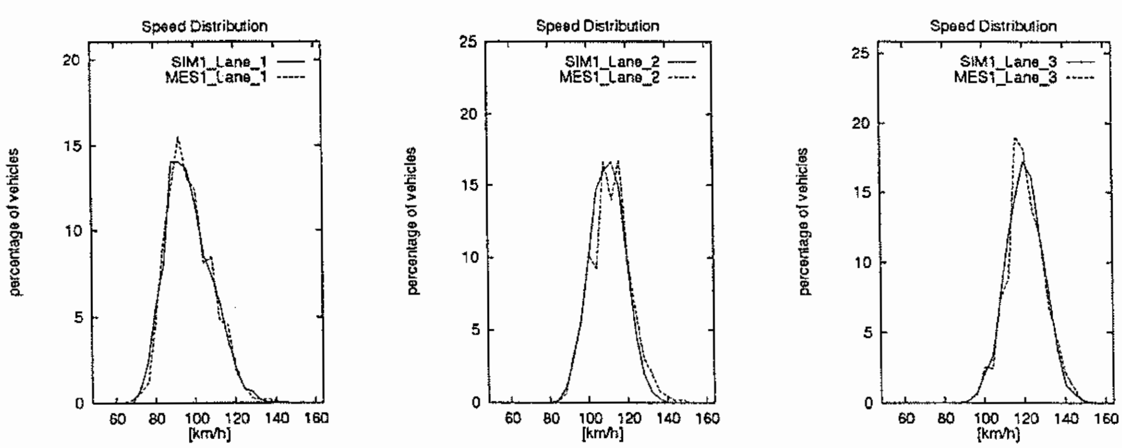


Figure 4: Speed distributions (MES1 vs. SIM1: right/middle/left lane)

2. Comparison of simulated data at the end with measured data at the end of the study section (MES2 vs. SIM2)
   The comparison shows, that some results differ considerably (up to 25 %). This can be explained as follows. The fact, that there is an exit following 400 m after the end of the study section, causes a change in the characteristics of the measured traffic. Therefore the intensity of the traffic (and the mean following distances) on all lanes differs from the data measured at the beginning of the study section. Since SIMCO3++ is currently designed to provide free traffic flow on a straight motor-way (see next paragraph), the influence of an approaching exit is currently not taken into account, but may be included in the set of mobility rules in the future.

3. Comparison of simulated data at the end with measured data at the beginning of the study section(MES1 vs. SIM2)
   In order to prove the ability of SIMCO3++ to provide a free traffic flow with constant statistical characteristics for several kilometres , the simulated data is compared with the data measured at the beginning of the study section (comparison between measured data at the end of the study section and SIMCO3++-data see previous paragraph). The data (see table 1 and figures 5 and 6) shows a good correspondence between simulation and measurements even after 2.9 km (maximal error below 10 %).

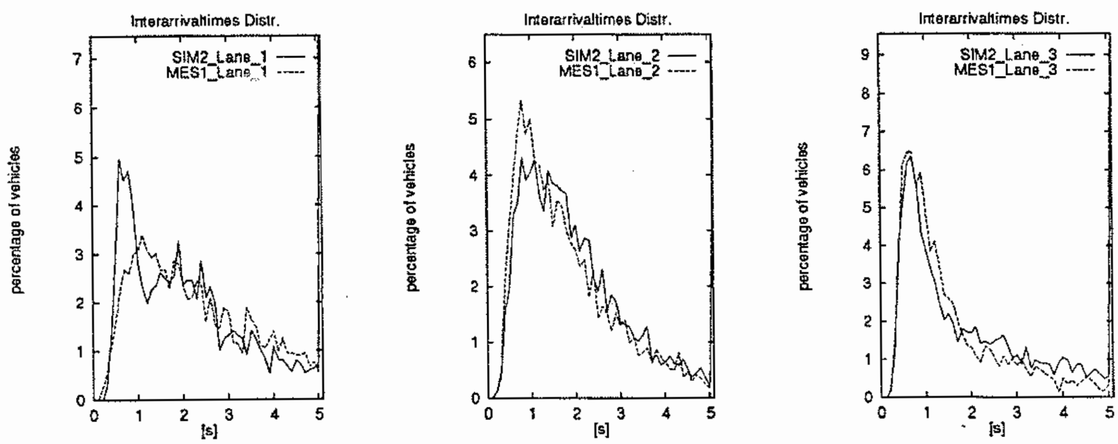


Figure 5: Interarrival times (MES1 vs. SIM2; right/middle/left lane)

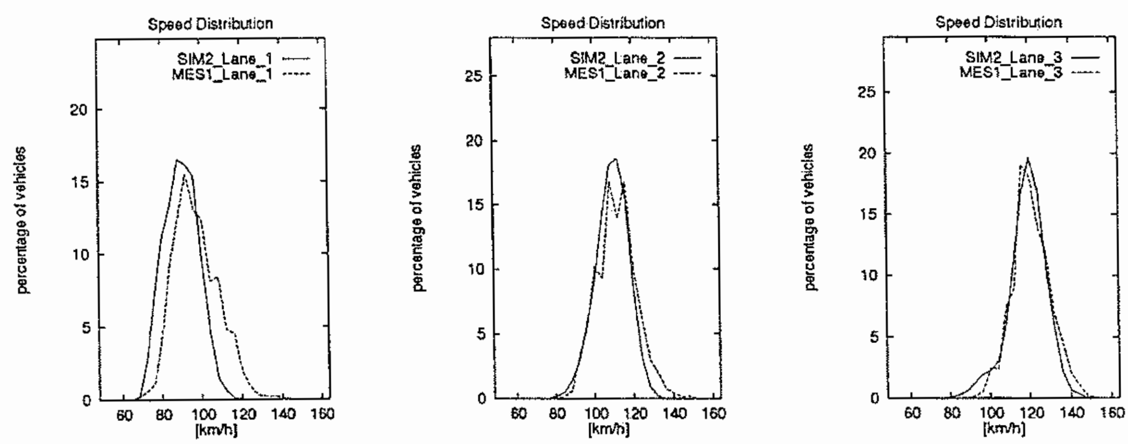


Figure 6: Speed distributions (MES1 vs. SIM2: right/middle/left lane)

## 7 Conclusions

In this paper, the functionality of the integrated simulation tool SIMCO3++ (SImulation of Mobile COmmunications), which has been designed for accurate analysis and performance evaluation of IRTE specific communication protocols (medium access control, logical link control, multi- hop routing strategies, etc.) for vehicle-beacon and inter-vehicle communications, based on realistic mobility models, road traffic scenarios has been presented.

A comparison of the motor-way measurements and the traffic scenarios simulated by SIMCO3++ shows a very good correspondence in important aspects like following distances between vehicles, average speed of vehicles, distribution of vehicle classes over the lanes especially at the generation point but also after a longer highway section. Therefore it can be concluded, that the simulator SIMCO3++ is a tool, which is very well suited for the performance evaluation of mobile communication protocols (short-range beacon-vehicle and inter-vehicle communications), which require the simulation of realistic road traffic mobility and scenarios.

Due to its sophisticated design, its modular concept, and its characteristic in combining very accurate communication protocol behaviour and channel characteristics with realistic mobility models for a variety of road traffic scenarios, SIMCO3++ provides not only valuable results for the evaluation, refinement and verification of the communication protocols, currently being developed by the communication projects of the DRIVE II programme (COMIS, GERDIEN, etc.), but also for the evaluation of proposed standards for beacon-vehicle communications (CEN TC 278; ISO TC 204), as well as for other mobile communication networks, like GSM (Public Land Mobile Network), UMTS (Universal Mobile Telephone System), MBS (Mobile Broadband System, RACE II Project), and any other large mobile communication network with a rapidly changing topology.

## 8 Acknowledgement

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