TOMAS APELTAUER, Ph.D.
E-mail: apeltauer.t@fce.vutbr.cz
JIRI MACUR, Ph.D.
E-mail: macur.j@fce.vutbr.cz
Brno University of Technology, Faculty of Civil Engineering
Institute of Computer Aided Engineering
and Computer Science
Veveri 331/95, CZ-602 00 Brno, Czech Republic
PETR HOLCNER, Ph.D.
E-mail: holcner.p@fce.vutbr.cz
MICHAL RADIMSKY, Ph.D.
E-mail: radimsky.m@fce.vutbr.cz
Brno University of Technology, Faculty of Civil Engineering
Institute of Road Networks
Veveri 331/95, CZ-602 00 Brno, Czech Republic

Traffic in the Cities
Review
Accepted: Mar. 16, 2012
Approved: Mar. 13, 2013

VALIDATION OF MICROSCOPIC TRAFFIC MODELS BASED ON GPS PRECISE MEASUREMENT OF VEHICLE DYNAMICS

ABSTRACT

A necessary stage in the development of traffic models is model validation, where the developed model is verified by comparing its outputs with observed data. The most frequently used variables are average value of speed, flow intensity and flow density (during a selected period).

It is possible to use these values for the calibration of macroscopic models, but one cannot always obtain a relevant microscopic dynamic model in this way. A typical use of the microsimulation models is the capacity assessment, where this sort of data (flow, speed and queues) is considered to be standard and sufficient. However microsimulation is also increasingly being used for other assessments (e.g. noise and emissions) where the correct representation of each vehicle's acceleration and deceleration plays a crucial role. Another emerging area is the use of microsimulation to predict near-miss situations and conflicts to identify dangerous and accident prone locations. In such assessments the vehicle trajectory, distance from other vehicles as well as velocity and acceleration are very important.

Additional source of data, which can be used to validate vehicle dynamics in microsimulation models, is the Global Positioning System (GPS) that is able to determine vehicle position with centimeter accuracy.

In this article we discuss validation of selected microscopic traffic models, based on the comparison of simulated vehicle dynamics with observed dynamic characteristics of vehicles recorded by the precise geodetic GPS equipment.

KEYWORDS

traffic flow; simulation; GPS systems; model verification; IDM model

1. INTRODUCTION

The movement of vehicles in the traffic flow is in terms of real traffic the simplest situation. In the basic scenario the traffic flow is studied in just one lane where vehicles must follow each other. Although the basic behaviour of a vehicle in this situation is well known, the exact dynamic processes in the traffic flow are not characterised enough and promise a wide field for further research. Although there are many traffic flow models, with some also being used in commercial products, it is little known how applicable and accurate they are when compared with the actual, empirically measured data [1].

For the traffic flow simulation the proposed model has to be verified using real data and the model parameters have to be adjusted to match the reality. The available data often come from profile detectors, which usually provide average values of the speed, intensity and traffic flow density for a specific time interval [2]. This data can be used to calibrate the model, especially in commercial packages, but for a detailed validation of vehicle behaviour in a dynamic microscopic model another data source needs to be found.

This paper discusses the validation of the selected microscopic traffic models using the dynamic characteristics of vehicles recorded by precise geodetic Global Positioning System (GPS) equipment.

Figure 1 - Photo of GPS antennas that are placed on the strap on the top of the vehicle. (Photographed during steady measurement of minimal vehicle distance)

2. FUNDAMENTALS OF MICROSCOPIC TRAFFIC MODELS

The basis of every dynamic model is the behaviour of individual vehicles and how this is related to their surroundings. One can assume that vehicle acceleration depends especially on its velocity v measured in m/s, the difference between the investigated (following) and the leading vehicle velocity Δv measured in m/s and the distance Δx between the two vehicles measured in m:

$$a = a(v, \Delta v, \Delta x). \tag{1}$$

The currently used models differ especially in the exact form of (1) and the implementation of other less important corrections such as reaction time, driver foresight, etc. For model validation the continuously measured values of both vehicle speeds and positions are needed, which also determines their relative distances. It is also important to collect the data from a set of predefined traffic scenarios.

In common modern vehicles the information about the vehicle speed is available from the Controller Area Network (CAN), which is the vehicle standard bus for external devices. The data from CAN is precise enough to be used in our model validation. Vehicle acceleration can be calculated using speed derivation or by using separate equipment (e.g. accelerometers).

The most difficult part is obtaining data about the relative speeds and vehicle distances. The values from the speed indicator are not accurate enough and numerical integration of speed contains irremovable error, which quickly increases.

To measure the distance between the leading and the following vehicle it would be necessary to add some type of a contactless distance detection device (laser beam for example) to the following vehicle and the whole experiment would be very complicated to perform. As we had neither the CAN bus connection, nor a distance detector, we tried to find another solution.

GPS systems could be used, but the most frequent ones on the market are not accurate enough. The location error is in metres and the frequency in seconds or more [3]. The Faculty of Civil Engineering at Brno University of Technology has been collecting geodetic measurements using the Leica GPS Systems with Navigation Signal Timing and Ranging Global Positioning System (NAVSTAR GPS) for a long time. Using this equipment one can perform precise measurements on two or more vehicles simultaneously. In the following example we measured the distance of two vehicles with centimetre accuracy. Our equipment also recorded the exact vehicle position every 100ms and was able to measure continuously for several hours.

Figure 2 shows a data preview collected at the end of the test stretch. Here, the vehicles turned around with one also reversing.

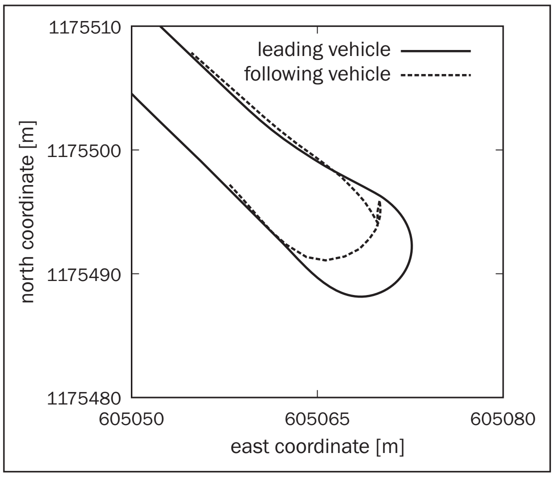

Figure 2 - Trace of two vehicles at the end of the test stretch

From the time series of the measured vehicle positions one can determine the vehicle velocities and accelerations. These are all the data that have to be used in (1) to verify the dynamic traffic flow model [4]. It should be mentioned at this point, however, that the interrupted traffic flow (dynamic interaction between two vehicles and obstacles) was empirically investigated in uninterrupted conditions. Yet, the findings are applicable for the traffic flow simulation in general.

The data dispersion is demonstrated in *Figure 3*, where one can see the data for a stationary vehicle.

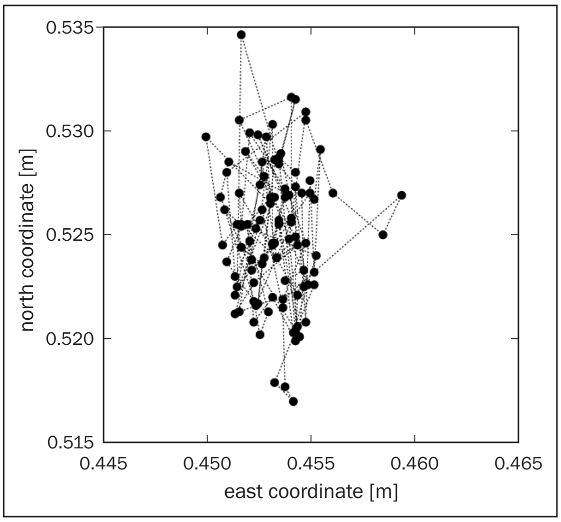

Figure 3 - Sample of stationary vehicle positions. Data dispersion is higher in the north-south direction due to less suitable positions of the visible satellites

If one approximates the vehicle behaviour from one measured interval of 100ms of uniform acceleration, the following formula for acceleration is used:

$$\delta a = 2\delta s/\Delta t^2, \quad (2)$$

where δs is the location error measured in m and Δt is the time step measured in s. Thus, for the location error of 1cm and time step of 100ms, the acceleration error is 2m/s^2. *Figure 5* shows that the computed instantaneous acceleration really oscillates in this range. An appropriate method such as polynomial approximation or moving averages can be used to compensate for this error. In the final statistical conclusions the quadratic errors from different driving phases were compared, calculated directly from the measured data not performing any approximation on these data sets.

3. ACCURATE GPS MEASUREMENT OF MOVING VEHICLES

GPS systems are routinely used for navigation and geodetic measurements. Our experiment requires both of these - navigation and highly accurate geodetic measurement from a long period of time. The results from the measurements in real time are not needed and therefore a post processing procedure could be applied to improve the accuracy of the collected measurements using data from a reference station.

In the experiment three professional Leica GPS System 500 geodetic devices were used capable of phase two-channel measuring. Two were placed on top of both vehicles and the third one served as a reference station and was placed nearby. Time synchronized data from devices were stored on high capacity memory cards and processed afterwards using software provided with Leica devices and own tools developed in Visual Basic for Applications (VBA) language.

3.1 Experimental conditions

The experiment was performed on the selected stretches of roads III/39528 and III/41619 between Hrusovany and Bratcice in the South Moravian region in the Czech Republic. The main criteria for selection of this area were:

- highway without shielding, overpasses, buildings and trees in the neighbourhood;
- low traffic intensity;
- small gradients and curvatures, road surface quality sufficient for vehicles driving at high speeds.

3.2 Validity of the model

The main goal of the experiment was the verification of a modified Intelligent Driver Model (IDM) [5] used for computer simulation experiments. This model can be viewed as interpolation of two variables – acceleration and deceleration. Formula (1) can be written in the following way

$$a_i = a_{i\,\mathrm{acc}} + a_{i\,\mathrm{dec}}. \quad (3)$$

Acceleration value can be calculated as follows:

$$a_{i\,\mathrm{acc}} = a_{i\,0} + (1 - (v_i/v_{i\,0})^{\delta}), \quad (4)$$

where $a_{i\,0}$ is the maximal achievable acceleration of the vehicle measured in m/s^2 and $v_{i\,0}$ the maximal vehicle speed measured in m/s. In this model, the dimensionless δ coefficient is calibrated to approximately $\delta \approx 4$ by the model developers [5]. Thus acceleration is a continuous monotone function of speed and vanishes at maximal speed.

The deceleration variable depends on the gap between vehicles Δs_i, and the optimal gap $\Delta s_{i\,\mathrm{opt}}$ between the vehicles for a given speed, both measured in m, as follows

$$a_{i\,\mathrm{dec}} = -a_{i\,0}(\Delta s_{i\,\mathrm{opt}}/\Delta s_i), \quad (5)$$

where $\Delta s_{i\,\mathrm{opt}}$ depends on the current velocity in the following form

$$\Delta s_{i\,\mathrm{opt}} = \Delta s_{i\,0} + \Delta v_i T_i + v_i \Delta v_i / 2\sqrt{a_{i\,0} b_{i\,0}}. \quad (6)$$

Parameter $\Delta s_{i\,0}$ is the distance at zero velocity measured in m, v_i is the current vehicle velocity measured in m/s, Δv_i is the relative velocity of both vehicles measured in m/s and T_i is the time gap from the leading vehicle measured in s, which is considered to be optimal for the driver.

The IDM model is relatively simple and efficient – it is important that the course of the individual accelerations is continuous, which corresponds to the empirical observations. It fulfils the basic requirements of traffic flow models:

- Collisionless course of performed simulations from the complete spectrum of possible parameters and initial conditions;
- Physically reasonable values of speed and acceleration of vehicles during the course of the simulation;
- Asymmetric characteristic of the model – the course of acceleration is different from the one of deceleration (usually a more abrupt deceleration is acceptable for example, in case of a risk of collision);
- Occurrence of global states corresponding to real observations – non-linearity of the model (stop-and-go waves; spontaneous occurrence of congestions at over-critical densities; hysteresis of the intensity of the traffic flow at over-critical and below-critical densities etc.).

Spontaneous occurrence of non-homogeneities was also proved (distances among vehicles and speed change in time and on track) in the case of identical simulated vehicles [9].

Suggested parameters of IDM model corresponding to normal vehicle behaviour in a traffic flow are as follows: $a_0 = 1.0$ m/s^2, $b_0 = 1.5$ m/s^2, $s_0 = 2$ m, $v_0 = 30$ m/s, $T = 1.8$ s, vehicle length $d_i = 5$ m [5]. As extreme situations with a single driver were also tested, the parameters for these cases were adjusted as follows: $a_0 = 3.0$ m/s^2, $b_0 = 5.0$ m/s^2, $v_0 = 33$ m/s. The following chapters describe one scenario corresponding to normal vehicle behaviour and three basic scenarios simulating extreme situations.

3.3 Two following vehicles

The most important part of our experimental measurements was a parallel observation of two vehicles in various situations. The complete tested scenario was as follows:

- The leading vehicle moves at a constant speed.
- The following vehicle starts and accelerates approaching the leading car.
- The following vehicle decelerates and synchronizes its velocity with the leading vehicle.
- Both vehicles move at the same velocity.
- The leading vehicle brakes to a full stop.
- The following vehicle must decelerate behind the leading one.

The observed GPS record of the first (leading) vehicle along with the observed and simulated results of the following vehicle is illustrated in *Figure 4*. As can be seen, a good concordance between the observed and simulated results was achieved with non-extreme basic parameters.

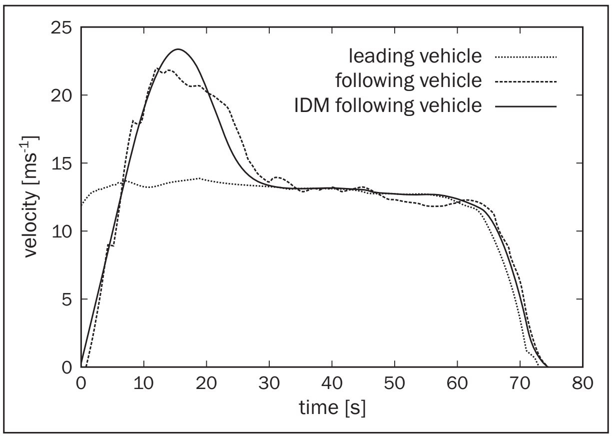

Figure 4 - Record of a scenario for IDM verification. The following vehicle caught up with the leading vehicle, then after some synchronization both vehicles decelerated to a full stop.

The manoeuvres of the testing driver are obviously not as smooth as in the case of IDM simulation; however, the model describes the general behaviour very realistically. The accuracy of IDM model is rather surprising, especially if one takes into account the complexity of the tested scenario, which included acceleration using full power of the engine, gentle deceleration by the engine, braking and approach manoeuvres with gap and velocity corrections.

3.4 Acceleration on a free road

In this scenario the tested vehicle moved with maximal achievable acceleration. By comparing data from IDM simulation with data recorded with GPS devices (*Figure 5*) one can conclude as follows:

- Considerable part of the acceleration phase (almost a third of the total time) is gear changing, during which the car does not accelerate. This acceleration discontinuity might be significant for the traffic flow and it should be verified by corresponding simulation experiments in the future.

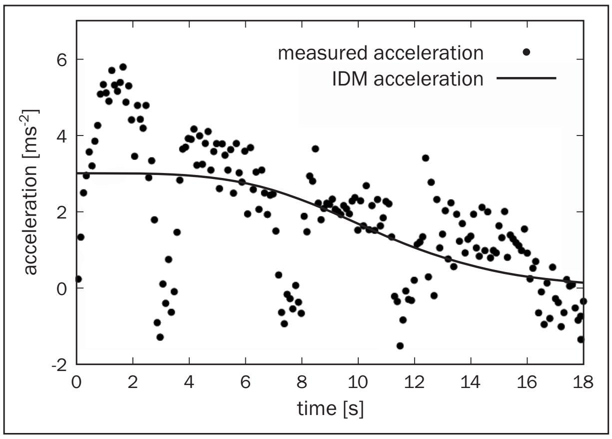

Figure 5 - Comparison of the observed maximal acceleration with IDM simulation

- The measured trend of velocity agrees with the IDM model and the IDM model is considered fully realistic.

3.5 Stopping behind an expected roadblock - stop braking

In this scenario the driver can see the roadblock and chooses easy continuous deceleration. Based on comparing the observed and simulated results (*Figure* 6) one can state the following:

- In the first phase (75s – 79s) the deceleration of the real vehicle is slightly higher than in the case of IDM simulation.
- Minimal value of deceleration is reached sooner in the case of IDM simulation (82s) and at higher velocity than in the case of a real vehicle (83s – 84s).
- A driver in a real situation is not able to estimate the stopping distance so accurately as the IDM model, therefore, the measured vehicle needs to correct its acceleration at the end of the trajectory.

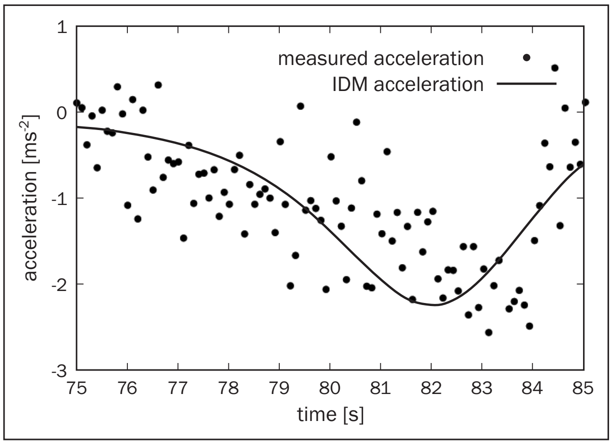

Figure 6 - Vehicle acceleration during stop braking in comparison with the IDM model

3.6 Stopping behind an unexpected roadblock - emergency braking

In this scenario the tested vehicle decelerated from a velocity of 29m/s using the Anti-lock Brake System (ABS). One can see that the value of speed drops down almost linearly. The basic IDM model does not include emergency braking conditions. IDM simulation decelerates at unrealistically high rate during the first phase while in the second phase, the deceleration is too low. Good concordance between the IDM model and a real vehicle can be reached by simply limiting the maximal deceleration, which corresponds to limited deceleration of real vehicles due to limited tyre adhesion (see *Figure 7*). One can conclude the following:

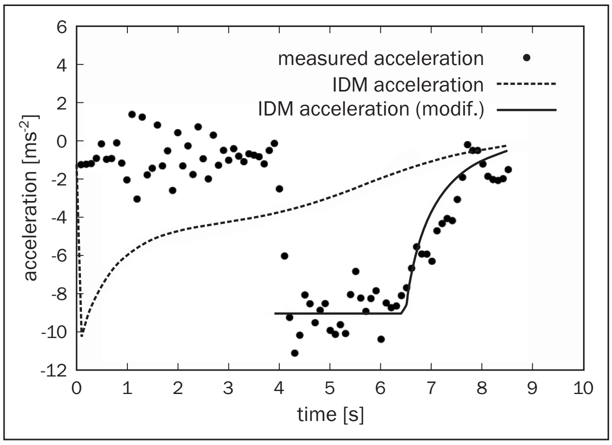

Figure 7 - Vehicle acceleration during the stopping behind an unexpected roadblock in comparison to the basic and modified IDM models

- Modified IDM model with limited maximal deceleration corresponds well to the observed values.
- When the calculated deceleration decreases to the adjusted limit, one can observe a fully realistic behaviour. In the last two seconds, the real driver was no longer in the ABS mode and braked with smooth deceleration as well.

3.7 Results evaluation and conclusion

If one wants to compare the agreement of the IDM model and the real measurements in these various scenarios, a suitable statistical variable must be found first. For these purposes the average quadratic deviation between the real measurements and the IDM model and the median of this deviation have been chosen. This allows estimating the distribution of this deviation, in other words, whether it is symmetrical or not. The following results were determined for the individual driving scenarios:

When looking at the results it is obvious, that the average deviation of the measurements from the estimates of the IDM model corresponds to the range

Table 1 - Statistical comparison of the different tested situations

Tested situations	Number of measurements	Average quadratic deviation	Median quadratic deviation
Two following vehicles	760	0.868m/s^2	0.250m/s^2
Acceleration on a free road	184	1.848m/s^2	0.616m/s^2
Stopping behind expected roadblock	112	0.358m/s^2	0.150m/s^2
Emergency braking	43	1.282m/s^2	0.907m/s^2

of values of the actual measurements. A good concordance with the IDM model was achieved in the first experiment, which is, in terms of its complexity, also the most common situation in real traffic. The best agreement was found in case of uniform deceleration. On the other hand, lower concordance can be seen in case of emergency braking, which even required model modification, and in case of maximal acceleration, where the model does not take into account gear changing. In general it can be concluded that the IDM model offers a much better approximation during standard situations than in case of critical events.

It should be emphasized that the model can be calibrated using direct measurements; however, the used model is not very sensitive to the parameters in standard situations. One must keep in mind that no model can ever exactly describe the various vehicle properties and driver habits (reaction time, anticipation, etc.). However, the theory of dynamic systems shows that in case of complex events the overall statistical characteristics of the system are often invariant, not just with respect to the parameters of the interaction model, but even to the model type itself. It is therefore necessary to choose the simplest model that corresponds to the normal expected behaviour. Adjusting the model too precisely makes no sense because of the deviations due to particular vehicle properties and driver habits.

In a simulation with a higher number of vehicles (hundreds and thousands) it can be seen that mass events (spontaneous congestion formation, its amplitude, speed, spread, etc.) are relatively independent of the particular interaction model and in fact have even very similar statistical characteristics; even in case when the vehicle properties (acceleration, deceleration, distance lag, etc.) are modelled using normal distribution with high dispersion [9]).

During unusual driving situations, the following deviations from the model can be seen:

1. In case of maximal acceleration, the model does not take into account changing of gears. However, in normal traffic this sort of situation is almost never seen; there is no need to accelerate from zero to maximum speed at a maximal rate.
2. For standard situations of vehicle following and comfortable acceleration and deceleration however, the model agrees quite well with the real data.
3. Model estimates for maximal deceleration are also adequate as no gear changing takes place.

Determining the parameters of the model using measurements from standard car following scenario (for example by nonlinear regression) is virtually impossible. The uncertainty of the parameters is too high and so the model corresponds to the measured values in a very broad range of parameter values.

4. COMPARATIVE ANALYSIS WITH OTHER WIDELY USED MODELS

The next part describes the comparison of the widely used Wiedemann's, or very similar Fritzche's car following models, belonging to a group of the so-called psycho-physiological models, with the previously described IDM model and real data.

4.1 Car following regime

Psycho-physiological models use the same set of parameters as other traffic models – the distance from the leading vehicle, relative speed between vehicles and the vehicle speed itself. Most important is the relation between the vehicle distance and its relative speed which determines the consequent driver's reaction. This can be represented in a diagram with borderlines which delimit different states. This is illustrated in *Figure 8* which shows areas related to Wiedemann's model. It is important to know that the driver state is also determined by the vehicle velocity itself, so this diagram is only one layer which corresponds to one driver speed. At various driver speeds, the borderlines also move slightly.

Fritzsche's model uses a similar procedure, but it defines limits in a different manner and different formulae are also applied to determine the acceleration. A detailed description containing definitions of the limits of the individual driving regimes is available in Literature [6, 7].

Both mentioned models postulate one very important thing – if there is an optimal combination of speed, relative speed and distance between ve-

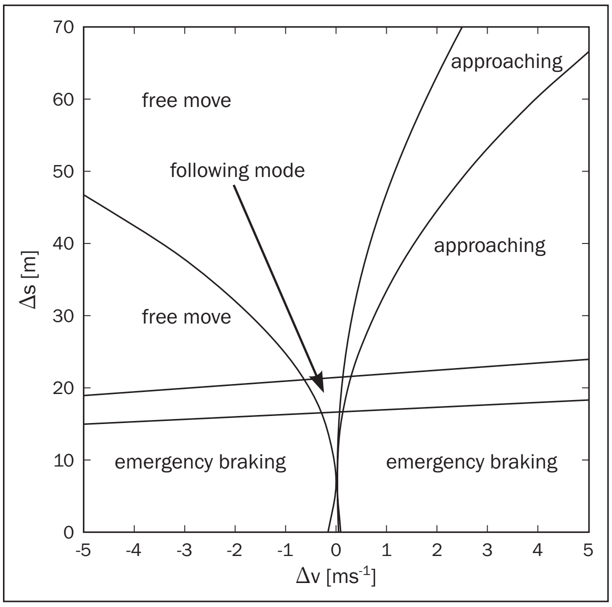

Figure 8 - Diagram of the Wiedemann's microscopic model which introduces four driving regimes

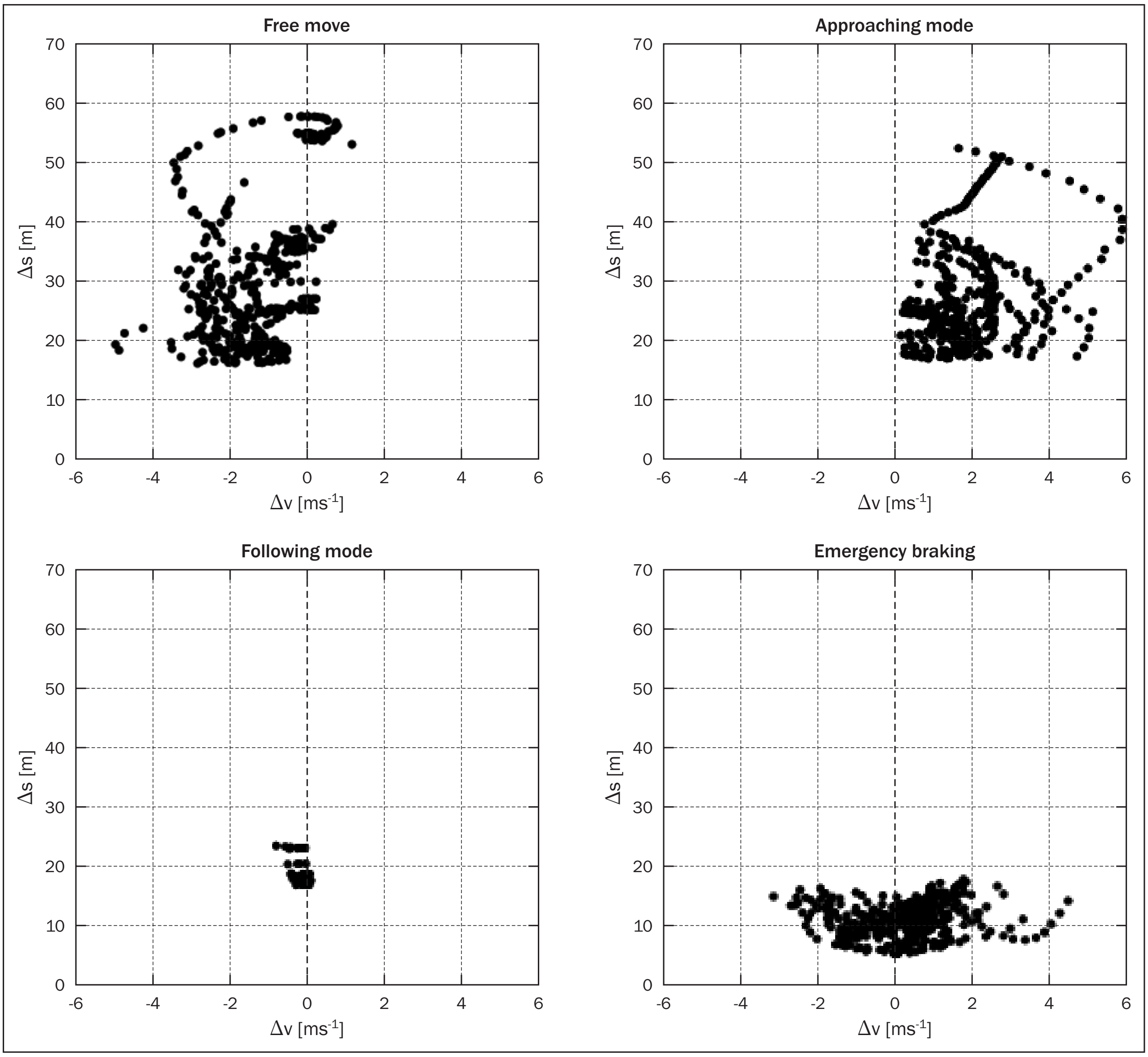

Figure 9 - Measured values for the Wiedemann's microscopic model

hicles, the vehicle itself remains in so-called "following mode" until these variables change, which means until the leading vehicle changes its speed. However, both models try to respect the speed fluctuations of vehicles and introduce non-zero acceleration within an interval of ±0.1 m/s^2. Acceleration and deceleration alternate when the border of the area of the following mode is reached. The considered area of car following regime is relatively small, as shown in *Figure 8*.

We have tried to verify these assumptions using real data obtained in the same way as described in the previous section. The measurements showed larger variation in distances and relative speeds, the target following state was very unstable. Typical behaviour of the difference in the speed-distance relation measured using real vehicles is visualised in *Figure 9*, and it is in compliance with the available measurement results of other authors [8].

Measured and plotted values are evaluated according to the Wiedemann criteria. Only a small portion of the measurements is plotted in the following mode and the vehicles do not remain in this mode. Free flow (free move state) and approaching mode prevailed and surprisingly, a large portion of states is evaluated as emergency braking.

The next step was a simulation of driving behind a leading vehicle moving at a constant speed using Wiedemann's model. The oscillations in acceleration in the car following regime are approximately ±0.1m/s^2 as expected, but also discontinuous fluctuations of acceleration up to +1.0m/s^2 have been observed, which does not correspond to the reality and could be a source of instability for a higher number of vehicles in a simulated traffic flow.

A natural extension of the experiment is the addition of another vehicle. It is demonstrated that the presumption of the car following regime is not fulfilled

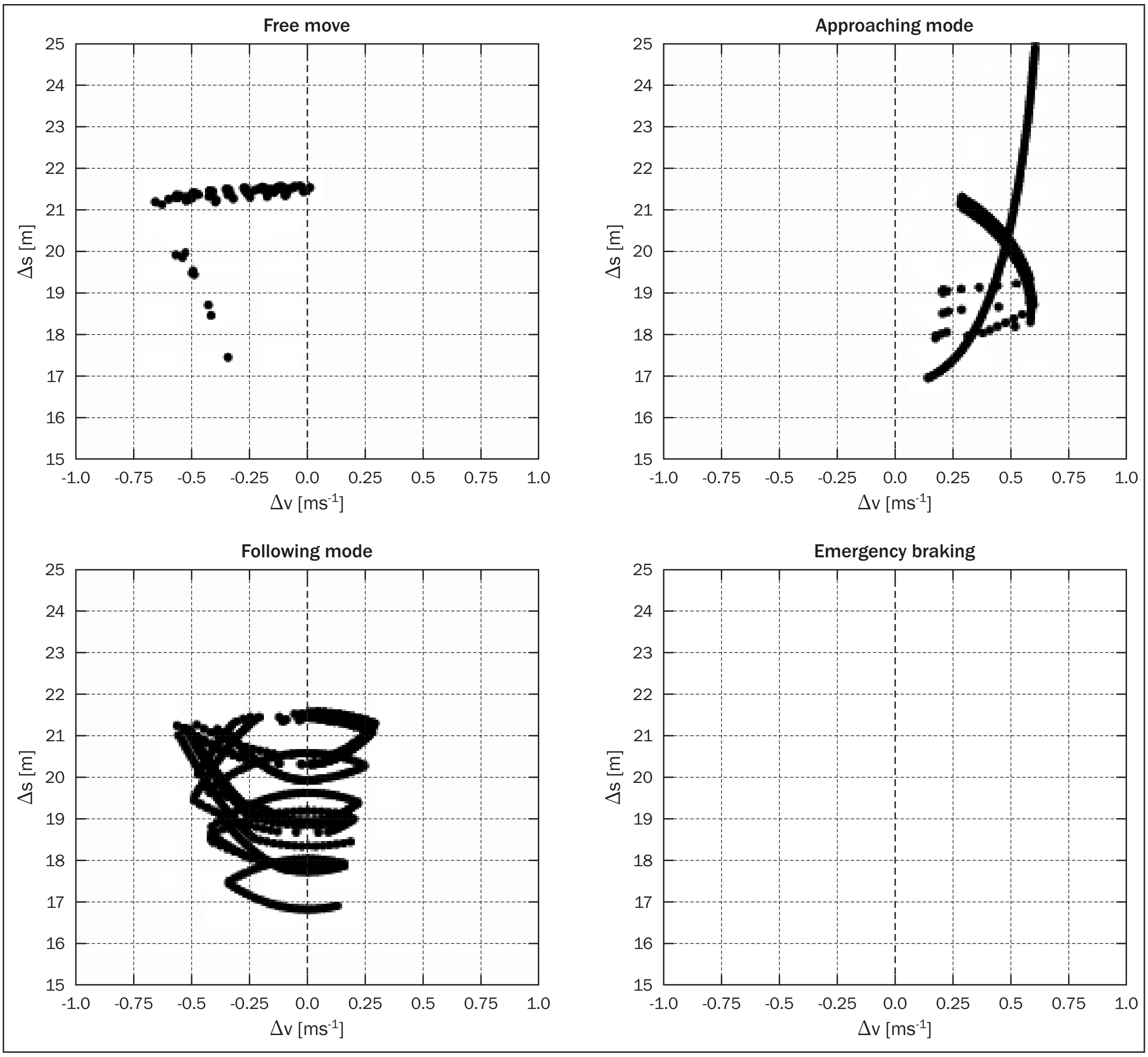

Figure 10 - Evaluation of regimes of simulated vehicle according to Wiedemann – plotted for the third vehicle in row, while the first one moves at a constant speed, the second and the third are controlled by Wiedemann's algorithm

and the described discontinuous course of acceleration becomes more evident. *Figure 10* shows the relation of the difference in speeds and distances of the third vehicle (the first moves at a constant speed, the second and third are controlled by Wiedemann's algorithm). The car following regime is still very unstable and vehicles quickly leave this area mainly into the approaching and free flow regimes. In this case emergency braking did not occur because the leading vehicle moves at a constant speed and the simulated vehicle reacts much more smoothly to the changes of the vehicle in front of it than a real vehicle does.

4.2 Simulation on a circuit

Further increase of the number of vehicles was performed in a simulated circuit with 250 identical vehicles. There is a requirement for every functional model to be collision-free and stable. However, due to the discontinuities mentioned above, this condition could not be achieved either by the basic Wiedermann's nor the Fritzsche's algorithms.

Satisfying results were achieved with the IDM model which has been studied by the authors' team in a previous work [9]. The model was implemented in a simulation tool developed by the authors' team in Java language where a large number of vehicles circulate autonomously on a circular track with a diameter of 1,000m.

In the simulation depicted in *Figure 11*, the states of vehicles were evaluated according to Wiedemann's criteria in the same way. The experiment with identical vehicles also did not prove tendencies of the IDM model to maintain the following mode. Most of the time the vehicle is in the free flow regime (labelled as free move) or in the approaching mode. As the situation

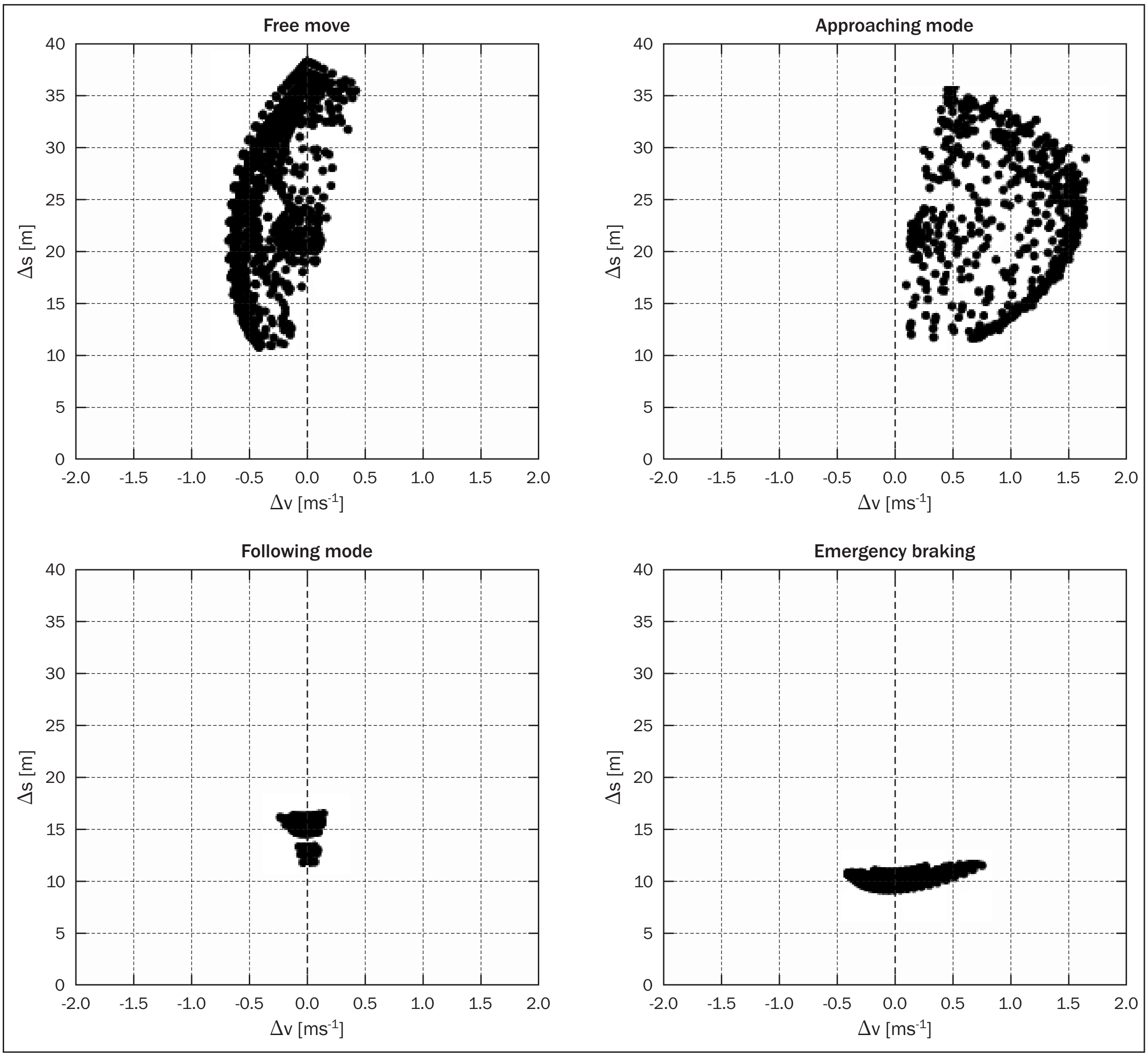

Figure 11 - Relation among the speed differences and distance differences for a simulated vehicle applying the IDM model on a circular track

on the track was much more complex and congestion spontaneously occurred, some states were evaluated as emergency braking.

A lower variance of speed as compared to real vehicles may be explained by the fact that constant speed was set for the simulated vehicles, while the leading vehicle purposefully changed its speed during the experiment with real vehicles.

5. CONCLUSION

GPS measurement enables universal position detection independent of the vehicle itself or other devices. Using the accelerometer might be suitable in order to obtain higher accuracy, but when sampling with sufficient frequency (> 10Hz) the acceleration can be simply calculated. On the other hand, achievable accuracy (< 0.01m) regardless of the vehicles velocity requires professional devices and a reference station (for two vehicles three GPS devices with phase measuring capability). When one studies the traffic flow models which are often in the foundations of the available program tools, we may find obvious contradictions with the real situations that were verified by the GPS equipment, and also with the very initial presumptions of such models. For example, the car following regime is not sustainable even if the leading vehicle drives at a constant speed being followed by two vehicles only. Despite this, these models are widely applied and results obtained accepted. This can be explained by the two following points:

- Authors of the models were interested mainly in the global, macroscopic, cumulative results suitable for practical application; in other words, the common average intensity and speed values of traffic flow. Therefore, behaviour of the individual vehicles at microscopic level is not so important. Simulation of specific traffic situations (entering a crossroad, overtaking, changing traffic lanes, traffic flows merging) is usually performed by means of ad hoc rules, which do not correspond to real possibilities of the simulated vehicle. Furthermore, the model is calibrated retroactively according to the statistic results of the simulation. Such a procedure naturally eliminates results which do not correspond to the standard expectations.

– Another reason for the successful existence of such models may be the stochastic nature of these models, which was intentionally eliminated. Such elimination enables studying the model basics. If one considers random characteristics, it is impossible to study synchronisation of behaviour and possible strengthening of their reactions.

Described experiments and experimental results showed significant differences in behaviour and relevance of the widely used models. The limiting factor for more specific conclusions is, however, incomplete range of tests which we have been able to perform. For a more complete picture other common situations in city traffic or on motorways should be implemented. Even the basic tests however, show a significant inconsistency in models used in commercial applications.

Generally, the determined problematic characteristics of the applied models do not constitute a reason for rejecting them. It should rather lead towards a different approach to the results modelling and their interpretation.

ACKNOWLEDGEMENT

This paper was elaborated with the financial support of the European Union's "Operational Programme Research and Development for Innovations" No. C2.1.05/2.1.00/03.0097, as an activity of the regional Centre AdMaS "Advanced Materials, Structures and Technologies".

TOMAS APELTAUER, PhD
E-mail: apeltauer.t@fce.vutbr.cz
JIRI MACUR, PhD
E-mail: macur.j@fce.vutbr.cz
PETR HOLCNER, PhD
E-mail: holcner.p@fce.vutbr.cz
MICHAL RADIMSKY, PhD
E-mail: radimsky.m@fce.vutbr.cz
Vysoké učení technické v Brně, Fakulta stavební
Veveří 331/95, 602 00 Brno, Česká republika

ABSTRAKT

VALIDACE MIKROSKOPICKÝCH DOPRAVNÍCH MODELŮ S VYUŽITÍM PŘESNÉHO GPS MĚŘENÍ DYNAMIKY VOZIDEL

Nezbytnou částí procesu vývoje dopravního modelu je jeho validace, kdy model verifikujeme oproti reálným datům. Nejčastěji využívanými veličinami v tomto procesu je průměrná rychlost, intenzita dopravního proudu a jeho hustota za zvolený časový interval.

Tyto veličiny sice můžeme využít pro kalibraci makroskopických modelů, nicméně pro kalibraci mikroskopických modelů musíme zvolit jiný postup. Typickým využitím mikroskopických modelů je kapacitní posouzení, kde tento druh empirických dat (intenzita dopravního proudu, rychlost, délka kolony) může standardně dostačovat. Mikrosimulace se nicméně stále více využívají také pro hlukové nebo emisní studie, kde je správná reprezentace dynamických vlastností každého jednotlivého vozidla zcela klíčová. Další rozvíjející se oblastí je využití mikrosimulací pro predikci potenciálně nebezpečných situací zejména na křižovatkách a následná identifikace rizikových oblastí. Zde je naopak velmi důležitá přesná trajektorie vozidel, vzájemný odstup, stejně jako jejich rychlost a zrychlení.

Dodatečným a velmi užitečným zdrojem dat tak může být systém GPS, který s využitím profesionálních geodetických aparatur umožňuje sledovat pozice vozidel s centimetrovou přesností.

V tomto článku se zabýváme validací vybraných dopravních modelů založenou na srovnání dynamiky simulovaných vozidel v rámci studovaných modelů a dynamických charakteristik reálných vozidel získaných prostřednictvím přesné geodetické aparatury.

KLÍČOVÁ SLOVA

dopravní proud; simulace; GPS systémy; verifikace modelů; IDM model

REFERENCES

[1] **Olstam, J. J.** and **Tapani, A.**: "*Comparison of car-following models*", Tech. rep., Swedish National Road and Transport Research Institute (2004)

[2] **Helbing, D.**: "*Empirical Traffic Data and Their Implications for Traffic Modeling*", Physical Review E 55, R25 (1997)

[3] **Muzik, J.** and **Gavulova, A.**: "*Traffic Data Processing with Integrated GIS and GPS*". In Journal of Informa-

tion, Control and Management Systems, Vol. IX, No.3, (2011), ISSN: 1336-1716

[4] **Chandler, R. E.**, **Herman, R.** and **Montroll, E.W.**: "*Traffic Dynamics: Studies in Car Following*", Operations Research 6, 165–184 (1958)

[5] **Treiber, M.**, **Hennecke, A.** and **Helbing, D.**: "*Congested Traffic States in Empirical Observations and Microscopic Simulations*", Physical Review E 62, 1805-1824 (2000)

[6] **Wiedemann, R.**: "*Simulation des Straßenverkehrsflusses*" Schriftenreihe des Instituts für Verkehrswesen Vol. 8, Institut für Verkehrswesen, Universität Karlsruhe (1974)

[7] **Fritzsche, H.T.**: "*A model for traffic simulation*", Traffic Engineering and Control, 35(5), 317-321 (1994)

[8] **Brockfeld, E.** and **Wagner, P.**: "*Calibration and Validation of Microscopic Traffic Flow Models*". In: Traffic and Granular Flow '03, Springer-Verlag Berlin Heidelberg (2005)

[9] **Apeltauer, T.**, **Holcner, P.** and **Macur, J.**: "*Pattern Formation in Traffic Microscopic Model*", in Traffic and Granular Flow '07 pp. 259–264 (2009)