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MEASURING AND MODELLING OF THE TRAFFIC FLOW AT MICROSCOPIC LEVEL

ABSTRACT

The traffic flow theory is dealing with the better understanding of the traffic flow and its improvement. Most often, the researched subject was been the road traffic. It is namely that heavy traffic and traffic jams are the frequent phenomena on the roads.

The traffic flow theory incorporates the different areas of knowledge necessary to establish a successful traffic-flow simulation model. Good correlation between the simulation model results and data collected in the open road conditions are not the only conditions which are necessary to approve the simulation model as accurate. The obtained simulation results may be used for the improvement of traffic conditions, only if the model obeys the classical laws of physics.

This paper is dealing with the simple microscopic model for two-vehicle-platoon behaviour in the traffic flow. The model is based on solving of the delay differential equations. The simulation model results have been compared with the measurement results. The comparison has enabled assessment of the selected simulation model to check whether it would be good choice for further traffic-flow researches at the microscopic level.

KEY WORDS

traffic flow, microscopic model, delay differential equations

1. MODELS OF THE TRAFFIC FLOW

Some of the models have already shown good simulation of the real life traffic conditions. However, a lot of them were useless for road-condition improvement, as they were not in compliance with the real-life road-conditions. For example the 'jump model' which deals with individual vehicles as if they were moving blocks, is one of them. The name of the simulation model and the way it deals with the road traffic participants is the same as the one for railway traffic. Furthermore, such unsuccessful modelling was a model which relied on the chaos theory. It does not consider any condition typical for road traffic. The truth is that a great number of the road conditions are, at first sight, of chaotic nature; however, they can be explained by the accident theory, road geometry or by virtual narrowness on the road.

2. SETUP OF EXPERIMENTAL SYSTEM AND DEFINING THE MEASURING CONDITIONS

For measuring of position, speed and vehicle-to-vehicle separation two AllStar Type GPS receivers, CMC Electronics Canada products, have been purchased: The basic forms (Option 1: 1 Hz phase measurement @ 19200 Baud) and supplemented forms for all differential corrections (Option 12: WAAS/EGNOS-DGPS). The only difference between them is their software. Both receivers are equipped with the outside antenna, which can amplify the signals up to 26dB. Navigation embedded OEM receiver AllStar, has 12 independent input channels and sends navigation data to the master computer at 1Hz frequency. It can indicate a position with an accuracy of less than 1m, if it gets the correction signal from GPS; otherwise, its indication is of accuracy to less than 16m. The price for such receiver basic version does not exceed 5% of the price for the latest designed embedded navigation receiver products.

For 4509 results processed, one measurement of selected geodesic point was carried out, on a randomly selected day and hour, to verify the position defining static accuracy of the Allstar-basic-version navigation receiver. At the interval of 95% reliability, the standard deviation of the measured width was ±1.32E-5 and the length ±1.12E-5. Within such interval of reliability all the results were scattered in a rectangular 3,906 m wide and 3,125 m long. The measured position average value, after static accuracy verification of the Allstar-basic-version navigation receiver, differs from the geodesic-point official position by $\Delta = 5.00$ m. All the measured results were scattered around the geodesic point in a circle of a radius $d_1 = 7.72$ m.

For dynamic accuracy measurement, the ring road has been chosen on purpose, since all the difficult conditions for positioning the vehicle by the satellite navigation system were located on such a road: cover up by a skyline by buildings, tree lane and an extensive water surface in the close vicinity (Figure 1). Every phase of measurement was composed of 3 drives. Each drive started and finished at the same marked location. The dynamic accuracy for each measurement was estimated from the difference between the collected data on positions at the beginning and at the end of the measurement, as the tour started and finished at the same location. The measurements have shown that, keeping the same interval of reliability, the standard deviation has increased by factor 2.09 in width and by factor 2.8 in length. The collected data on vehicle positions for the same location, at dynamic measurement, have average deviation value 4.72m or approximately the length of a passenger car. The speed limit in inhabited places is $v \leq 60\text{km/h} = 16.67\text{ms}^{-1}$. Such limitation very often led to the bumper-to-bumper driving platoons. This is the reason why, for the aims of this research, such speed has been chosen as the measuring speed of the vehicles in traffic flow.

Researchers of the two-vehicle platoon behaviour in traffic flow have performed various disturbances referring to the type and objectives of the research [3]. Regarding the purpose and objectives of this research the selected disturbance for the two-vehicle platoon was acceleration and then deceleration down to the initial speed of the leading vehicle in the platoon.

To define the average value of the following vehicle response, for each measurement at least three data for the selected 3 different disturbances were made. Such data are to be used for the next phase of this research and that is checking the possibilities of predicting the statistical traffic flow behaviour by means of the Kalman filter.

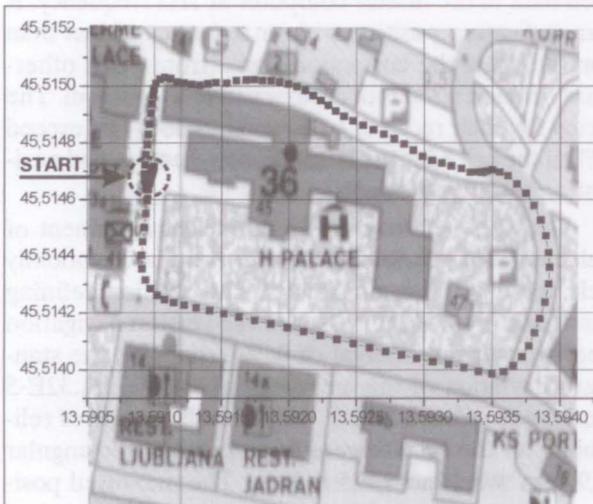

Figure 1 - Drive along the ring road was performed at average speed 5.364 ms^{-1} or 19.3 km/h

3. TRAFFIC-FLOW MICROSCOPIC MODELS

The initial equation of the relationship between the leading (n+1) and the following (n) vehicle in the platoon presented the classical microscopic model of two-vehicle platoon behaviour in the traffic flow.

$$\frac{d^2 x_{n+1}(t+T)}{dt^2} = \lambda \left[\frac{dx_n(t)}{dt} - \frac{dx_{n+1}(t)}{dt} \right] \tag{1.1}$$

This model incorporates the factors of the driver's sensitivity such as time lag for the driver of the following car T and his response to the disturbance λ. The response of the driver to the disturbance λ is also called sensitivity factor or amplification factor. Classical model is rather general and it cannot describe the specific conditions of road traffic. Therefore, some authors have proposed the improved models, which can describe some of the events being specific for road traffic [4, 5, 6].

Such improved model (model California) can define vehicle-to-vehicle separation with better accuracy. The length of the leading vehicle L was also taken into consideration together with its response time T_1 (1.2).

$$\frac{d^2 x_{n+1}(t+T)}{dt^2} = \lambda \left[x_n(t) - x_{n+1}(t) - L - T_1 \frac{dx_{n+1}(t)}{dt} \right] \tag{1.2}$$

The classical model of the two-vehicle platoon behaviour in the traffic flow is less suitable for the description of heavy-traffic. In compliance with this model the unstable vehicle drive shall lead to a mutual race.

Therefore, the improved model [5] was established, where $h = x_n - x_{n+1}$ is vehicle-to-vehicle separation (1.3). In this model only the following-vehicle response to disturbance was taken into consideration.

$$\frac{d^2 x_{n+1}(t)}{dt^2} = \lambda \left[\hat{v}(h_{n+1}) - \frac{dx_{n+1}(t)}{dt} \right] \tag{1.3}$$

In the improved model of two-vehicle platoon in the traffic flow, the speed function $\hat{v}(h)$ was also introduced, which has to fulfil the condition (1.4).

$$v_{\max} = \lim_{h \to \infty} \hat{v}(h) \tag{1.4}$$

The condition of stability for the improved model (1.3) can be defined (1.5), where b is vehicle-to-vehicle separation in the stationary traffic flow.

$$\left. \frac{d\hat{v}(h)}{dh} \right|_{h=b} = \frac{d\hat{v}(b)}{db} < \frac{\lambda}{2} \tag{1.5}$$

4. DELAY DIFFERENTIAL EQUATIONS

Delay differential equations have incorporated time delay τ and can be presented in the simple way (1.6) and in the more complex way [7] as well.

$$y'(t)=f(x,y(x),y(x-\tau)) \tag{1.6}$$

The solution of such equation depends on instantaneous and previous values. The differential equations describe the real physics systems behaviour very well, and can be used even to predict the behaviour of the physics systems whose response is not known from real life or is non-linear.

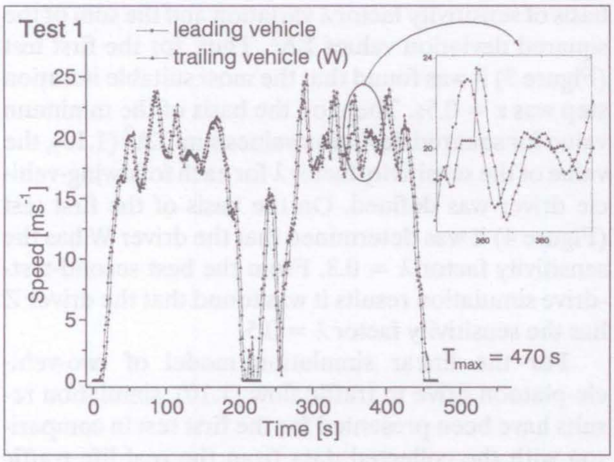

Figure 2 - Graph $v(t)$ for the first test drive of the two-vehicle platoon in traffic flow

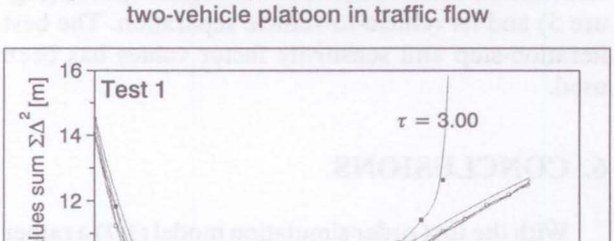

Figure 3 - Iteration step τ dependence on sensitivity factor λ and squared deviation values sum $\Sigma\Delta^2$ variation for the first test

The time-delay value $x-\tau$, in the delay differential equation (1.6) is limited by the positive value of the independent variable x. If the solution of delay differential equation is known and assuming that it is $\varphi(x)$ then $y(x)=\varphi(x)$ for each value of x in the range $(x_0-\tau)\le x\le x_0$; the existence of such solution could be easily proved. If the function $y(x-\tau)$ can be defined for each x in the range $x_0\le x\le(x_0+\tau)$ then equation (1.6) becomes the ordinary differential equation. Such equation can be governed as ordinary differential equation, which can be solved by the theorem on existence of solutions. If in accordance with theorem on existence of solutions, the value y(x) is known for each value $x_0\le x\le(x_0+\tau)$ then the solution for values $(x_0+\tau)\le x\le(x_0+2\tau)$ can be also found.

If Runge-Kutta method is used for governing of the delay differential equation, assuming that the time delay value τ is constant, the obtained solution should be dependent from the previous solutions [7]. That is why the Runge-Kutta method is numerical analogy for the solution of the delay differential equations (1.6) by ladder estimation.

Modern methods for numerical solution, which resulted from the Runge-Kutta method, enable delay differential equations solution also in cases with inconstant time delay value τ. For designing such methods the Retard software tool has been used. The source code of the Retard program is written for Fortran compiler. It is composed of the driver and a subroutine. It arose from the program DOPRI5, which was developed in 1987 by Dormand and Prince. DOPRI5 is meant for numerical methods for solving differential equations y' = f(x, y) using the fifth order Runge-Kutta - method with dense outlet of the fourth order [8].

5. DYNAMIC-MODEL DESIGN BY RETARD SOFTWARE TOOL

The linear simulation model of vehicle following in the traffic flow (1.7) was designed in the main program of the Retard software tool.

$$\left.\frac{dv_2(t)}{dt}\right|_{t+\tau}=\lambda[v_1(t)-v_2(t)]_t \tag{1.7}$$

τ – time delay, iteration step;

λ – driver sensitivity.

The data on driver speed were collected from the real life traffic flow by tracing two-vehicle platoon and they are defined as: leading vehicle speed $v_1(t)$ and the following vehicle speed $v_2(t)$. The same was done for the first test (Figure 2); however, the time was standardized referring to its initial value using the Origin software tool. By means of the same software tool the route for single vehicle $s_1(t)$ and $s_2(t)$ was calculated using the data on changing of position. The difference Δv and Δs of collected data on speed and route was calculated as well (1.8).

$$\Delta v=v_2(t)-v_1(t) \tag{1.8}$$
$$\Delta s=s_2(t)-s_1(t)$$

On the basis of the collected data in the Retard main program, the leading vehicle acceleration $a_1(t)$

for single test was calculated by ladder estimation. At the same time the main program was the driver for Retard subroutine which performed the numerical integration. The Retard program was translated by means of Compaque Visual Fortran Compiler, Professional Edition Ver. 6.6B/2000 for Fortran 90 program language. The compiled Retard program runs in the Windows environment. The simulation results have been presented graphically using Microcal Origin Ver. 6.0/1999 software tool.

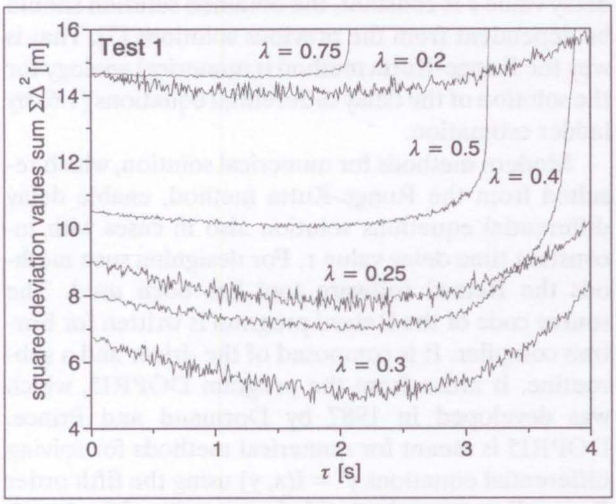

Figure 4 - Sensitivity factor λ dependence on iteration step τ and squared deviation values sum $\Sigma\Delta^2$ variation for the first test

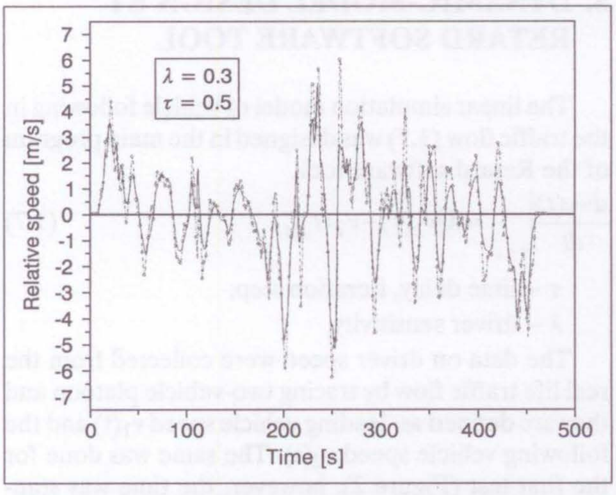

Figure 5 - The collected and calculated relative speed values at optimal sensitivity factor λ and iteration step τ for the first test

On the basis of the set-up model (1.7) the following car speed $v'_2(t)$ and route $s'_2(t)$ have been calculated by means of the Retard program. It was possible to calculate deviation for speed and route (1.9) for each step, using the collected data on the leading vehicle speed and the following-vehicle-speed values calculated from the simulation model.

$$\Delta\widetilde{v} = v_1(t) - v'_2(t)$$
$$\Delta\widetilde{s} = s_1(t) - s'_2(t) \tag{1.9}$$

After finishing each test simulation for this research on two-vehicle platoon behaviour in traffic flow, the sum of squared differences between collected data (1.8) and differences between the calculated data (1.9) was finally calculated and the sum of the squared deviation values $\Sigma\Delta^2$ for N iteration steps (1.10) was defined.

$$\Sigma\Delta^2 = \sqrt{\frac{\Sigma(\Delta s - \Delta\widetilde{s})}{N}} \tag{1.10}$$

The most suitable iteration step τ was selected on the basis of sensitivity factor λ variation and the sum of the squared deviation values $\Sigma\Delta^2$. Thus, for the first test (Figure 3) it was found that the most suitable iteration step was $\tau = 0.5$s. Then, on the basis of the minimum value for squared deviation values sum $\Sigma\Delta^2$ (1.10), the value of the sensitivity factor λ for each following-vehicle driver was defined. On the basis of the first test (Figure 4) it was determined that the driver W has the sensitivity factor $\lambda = 0.3$. From the best second-test-drive simulation results it was found that the driver Z has the sensitivity factor $\lambda = 0.5$.

For the linear simulation model of two-vehicle-platoon drive in traffic flow (1.10), simulation results have been presented for the first test in comparison with the collected data from the real life traffic flow: the differences between the vehicle speeds (Figure 5) and its vehicle-to-vehicle separation. The best iteration-step and sensitivity factor values has been used.

6. CONCLUSIONS

With the first order simulation model (1.7) a rather rough description of the driver's ability has been obtained, while the description with the third order simulation model was much more precise. The latter simulation model of higher order describes the driver's ability with two applicable parameters and not only with one, as in the first order model. For the future development of these models not only their applicability is important, but also further development of the methods of measurement and the measuring tools. Both of them should be standardized at the proper stage of the development. Which model will be given priority, that will be decided in the course of time depending on the opportunities given to researchers for gaining new knowledge and finding explanations for simulation results, and also on the qualification of the staff working with the particular model.

Such research is of practical value for the introduction of Intelligent Transport Systems, because it tests and estimates the real efficiency in increasing mobility, safety, productivity, and decreasing negative impacts on the environment [9]. Progressive introduction of such systems is changing our habits as road- and other transport way-users. Decisions on introduction of such systems should not be left only to market mechanisms, but have to be observed and verified on simulation models all the time. At a certain stage of development we will recognize that our lives have changed in the course of introducing the Intelligent Transport Systems and that transport systems themselves have changed as well. Which changes exactly can be expected, that is something that cannot be predicted [10].

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POVZETEK

MERITVE IN MODELIRANJE PROMETNEGA TOKA NA MIKROSKOPSKI RAVNI

Teorija prometnega toka se ukvarja z razumevanjem prometnega toka in njegovim izboljševanjem. Najpogostejši predmet njene raziskave je cestni promet. Avtomobilski promet po cestah se namreč najpogosteje gosti in zastaja.

Teorija prometnega toka vključuje večje število znanj z namenom, da se postavi pravi model prometnega toka. Velika korelacija med rezultati, pridobljenimi z modelom, in tistimi, pridobljenimi z dejanskimi meritvami prometnega toka, še ne opravičuje postavljenega modela. Model mora sloneti tudi na razumljivih fizikalnih osnovah, da se lahko pridobljeni rezultati uporabijo za nadaljnje izboljševanje prometnih razmer.

V prispevku je obravnavan enostaven mikroskopski model obnašanja dvojice vozil v prometnem toku. Naslanja se na reševanje diferencialnih enačb z zakasnitvijo. Rezultati simulacije so primerjani z merilnimi rezultati. Na osnovi te primerjave je nato ocenjena vrednost izbranega modela za nadaljnje raziskave prometnega toka na mikroskopski ravni.

KLJUČNE BESEDE

prometni tok, mikroskopski model, diferencialne enačbe z zakasnitvijo

LITERATURE

[1] **May, A. D.**: *Traffic flow fundamentals.* Englewood Cliffs: Prentice Hall, 1997. ISBN: 0139260722.

[2] **Gazis, D. C.**: *Traffic Theory.* International Series in Operations Research & Management Science, 50. Boston: Kluwer Academic, 2002. ISBN: 1402070950.

[3] **Agogino, A. M.** at al.: *Aggregation of direct and indirect positioning sensors for vehicle guidance.* Final Report. PATH Project MOU-322. Berkeley (US): University of California, May 31, 2000. ISSN 1055-1425. Available also from Internet for Adobe Acrobat: <http: //www. its. berkeley. edu/publications/ UCB/2000/PRR/UCB-ITS-PRR-2000-24. pdf>.

[4] **Rothery, R. W.**: *Car following models.* Traffic Flow Theory: A State of the Art Report: Chapter 4. McLean (USA.): U. S. Department of Transportation, Federal Highway Administration, Turner-Fairbank Highway Research Center, 1997. Available also from Internet for Adobe Acrobat: <http: //www. tfhrc. gov/its/tft/ tft. htm>.

[5] **Bando, M.** et al.: *Dynamic model of traffic congestion and numerical simulation.* Physical Rewiew E, February 1995, Vol. 51, No. 2, pp. 1035-1042.

[6] **Batista, M.**: *Numerical simulation of traffic congestion.* Proceedings. 3. mednarodno znanstveno - strokovno posvetovanje o prometni znanosti. Portorož, 7-9 October 1999. Portorož: Fakulteta za pomorstvo in promet, 1999, pp. 361-367.

[7] **Hairer, E., Norsett, S. P., Wanner, G.**: *Solving ordinary differential equations: Nonstiff problems.* 2nd Revised edition. Berlin: Springer Verlag, 2000. ISBN: 3540566708.

[8] **Hairer, E.**: *Fortran and Matlab codes: Nonstiff differential equations: DOPRI5* [online]. Genève (CH): Université de Genève: Section de mathématiques, 2002 [cited 23.01.2003]. Accession no. 26561. Available from the Internet as text file: <http: //www. unige. ch/math/folks/ hairer/software. html>.

[9] **Colyar, J. D.**: *An empirical study of the relationships between macroscopic traffic parameters and vehicle emissions.* Master Thesis. Raleigh (US): Graduate Faculty of North Carolina State University, 2001. Available also from Internet for Adobe Acrobat: <http: //www. lib. ncsu. edu/etd/ public/etd-463614521011630/etd. pdf>.

[10] **Zhu, B.**: *Potential effects on accidents from forward collision warning/avoidance system.* Master Thesis. International Master Program on Traffic Environment and Safety Management INT. Norrköping (S): Linköping University, 2001. Available also from Internet for Adobe Acrobat: <http: //www. itn. liu. se/~lenst/master/ thesis/ mtbozhu. pdf>.