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AN SLX-BASED MICROSIMULATION MODEL FOR A TWO-LANE ROAD SECTION

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ABSTRACT

A car-following and lane-changing microsimulation model of a two-lane road section has been written in SLX (Simulation Language with eXtensibility) as part of an extensive research project by the University of Rome Transport Department to qualify and quantify the environmental impact of traffic. The microsimulation model is part of a three-step approach, involving a traditional transport macroscopic model**,** the microscopic model, and an ultra-micro model. The microsimulation model's car-following and lane-changing rules are presented and described in detail, and model outputs are commented. The paper includes a short description of the Microsoft Visual Basic user-interface developed by the author and the animation performed by means of Proof Animation.

1 INTRODUCTION

Microsimulation models are frequently applied in analysis of transport systems. As basic and important components of such models, car-following and lane-changing models have been the object of considerable research interest since the 1980s.

Many **car-following** models have been developed (e.g., Gipps 1981, Aycin and Benekohal 1998). These have different levels of complexity, ranging from simplistic models proclaiming a fixed speed-distance relationship for all traffic situations to models with dedicated behavior modeling for different situations based on psychological research.

Similarly, **lane-changing** behavior has been studied extensively, and several models have been proposed and implemented (e.g., Ben-Akiva et al. 1995, Gipps 1986). As the importance of Cellular-Automata-based simulation had been recognized, minimal sets of rules were proposed for two-lane (Rickert et al. 1996) and multi-lane (Nagel et al. 1999) traffic.

A car-following and lane-changing microsimulation model of a two-lane road section has been implemented by the author. The model is written in SLX, Simulation Language with eXtensibility, the newest member of Wolverine Software's family of simulation and animation software (Henriksen 2000a).

The model is part of an extensive research project by the University of Rome Transport Department to qualify and quantify the environmental impact of traffic.

The microsimulation model is the second element of a three-step approach, comprising a traditional transport **macroscopic model** to identify traffic flows and speeds on each network link, a **microscopic model** to reconstruct vehicle driving-cycles in the network links, and an **ultra-micro model** to calculate consumption and emissions of all the vehicles in the links.

Microsimulation of each link will include both the upstream and the downstream nodes, taking into account:

1. vehicle arrivals on each link of the upstream node's backward star (i.e., the set of all links entering the upstream node; see Figure 1),
2. vehicle movements and interactions on the simulated link, and
3. vehicle departures on each link of the downstream node's forward star (i.e., the set of all links exiting from the downstream node).

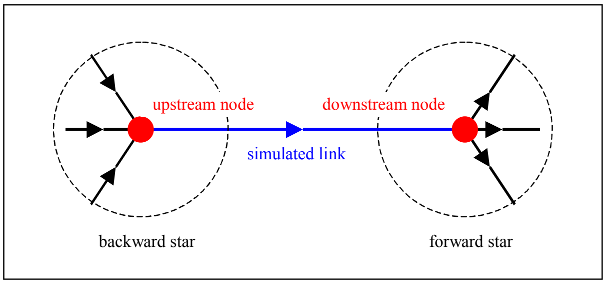

Figure 1: The Microsimulation Approach

The paper presents the microsimulation model developed to simulate vehicle movements and interactions on a two-lane link, at a distance from the upstream and downstream nodes to consider their influence negligible.

2 THE MODEL

2.1 Link Geometry

The model simulates vehicle movements and interactions on a two-lane road section. The section's length and the lanes' width are specified by the model user. A default length of 500 m and a default width of 3.5 m per lane are assumed if no user-defined values are input to the model.

2.2 Vehicle Types

Up to four different vehicle types can be specified:

- small cars,
- large cars,
- buses, and
- trucks.

The user may specify length and width for each vehicle class as well as choose a subset of classes for his analysis. Default values for vehicle lengths and widths are reported in Table 1.

Table 1: Default Values for Vehicle Lengths and Widths

Vehicle type	Length (m)	Width (m)
Small car	3.5	1.5
Large car	4.5	1.7
Bus	12.0	2.0
Truck	18.0	2.0

2.3 Flow Characteristics

A fundamental input for the model is the number of vehicles per hour per lane (**hourly flow**). The model allows the user to define for each lane i a time-dependent input flow, $q_i(t)$, according to the following:

$$q_i(t) = q_{0,i} + q_{1,i} \cdot t + q_{2,i} \cdot t^2 + q_{3,i} \cdot t^3,$$

where:

- i = lane (right or left),
- t = generic time instant,
- $q_{0,i}$, $q_{1,i}$, $q_{2,i}$, $q_{3,i}$ = flow parameters for lane i.

The flow parameters are lane-dependent and need to be specified as input. The model assumes a constant flow as default, i.e.: $q_{1,i} = q_{2,i} = q_{3,i} = 0$, $\forall$i.

The user can define the flow composition, quantifying percentages of cars, buses and trucks on each lane.

2.4 Desired Speed

The model assigns to each vehicle n an individually link-dependent **desired speed**, $v_{d,n}$, assumed to be normally distributed over the link macroscopic free-flow speed value. The macroscopic free-flow speed value is an input to the model, the standard deviation is assumed to be 10% of the macroscopic free-flow speed. The model user can specify maximum and minimum values for the desired speed, thus setting bounds to the distribution curve. Lane-specific values for the desired speed can be defined.

Since cars are usually driven faster than are heavy vehicles (buses and trucks), the average speed of cars on each lane i is Δv_i higher than the average speed of heavy vehicles (assumed to be equal to $v_{min,i}$, the minimum desired speed on lane i), with Δv_i given by:

$$\Delta v_i = \frac{\overline{v}_i - p_{h,i} \cdot v_{\min,i}}{p_{c,i}} - v_{\min,i},$$

where:

- $\overline{v}_i$ = macroscopic free-flow speed value for lane i,
- $p_{h,i}$ = percentage of heavy vehicles on lane i,
- $p_{c,i}$ = percentage of cars on lane i,
- $v_{min,i}$ = minimum desired speed on lane i.

The model assumes that vehicles with higher desired speeds are driven by more aggressive drivers. Higher desired speeds therefore imply shorter headway distances, greater deceleration/acceleration rates and more overtaking.

2.5 Car-Following

If the distance headway between a vehicle and its leader is greater than a pre-defined driver-specific critical distance (see below), the driver tries to maintain his desired speed (**free driving mode**).

In reality, owing to imperfect throttle control, the vehicle's speed oscillates around the desired speed (Fellendorf and Vortisch 2001). The driver therefore accelerates or decelerates unconsciously. The model assumes that such unconscious acceleration/deceleration is normally distributed around zero, with a standard deviation equal to ¼ of the maximum acceleration/deceleration. The normal distribution is bounded so that a pre-defined maximum acceleration/deceleration (assumed to be ± 2.5 m/s^2) cannot be overcome.

When the distance between the vehicle and its leader falls below the driver-specific **critical distance**, $d_{c,n}$, the driver decides, according to his aggressiveness (i.e., his desired speed), either to

1. change lane (in order to overtake the slower leader),

or to

2. decelerate and adjust his speed to the lower speed of the leader.

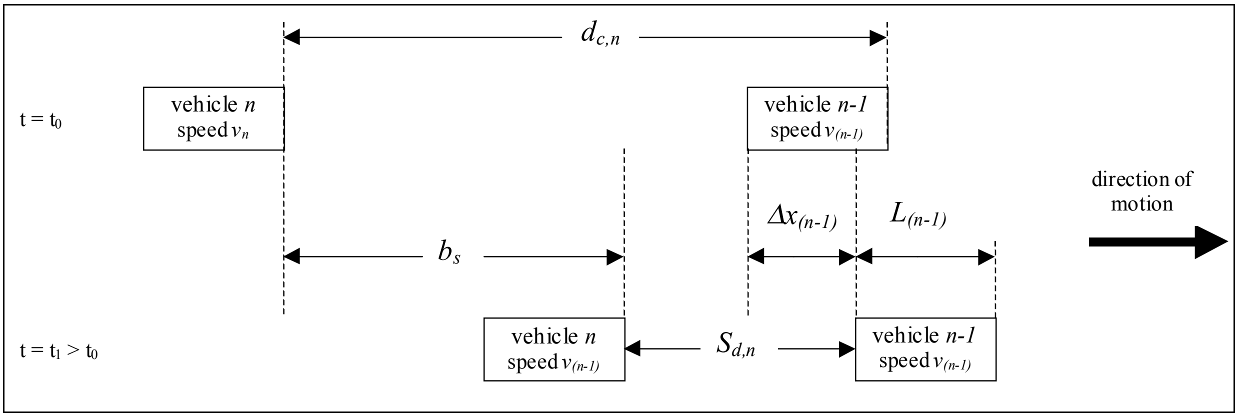

Figure 2: Critical Distance for Vehicle *n*

In the second case the driver starts an approaching phase (**conscious braking mode**) that will be completed when the speed difference of the two vehicles (follower and leader) is zero.

The **critical distance**, $d_{c,n}$, for the generic vehicle *n* is defined as follows:

$$d_{c,n} = b_s - \Delta x_{(n-1)} + S_{d,n} + L_{(n-1)}, \tag{1}$$

where:

- b_s = braking space for vehicle *n*, given by Equation (2),
- $\Delta x_{(n-1)}$ = leader advancement while the follower is braking, given by Equation (3),
- $S_{d,n}$ = stochastic following distance, given by Equation (4),
- $L_{(n-1)}$ = leader vehicle's length.

Critical distance and its component terms are shown in Figure 2.

Equation (1) is updated every 0.1 second, taking into account any changes (in speed or lane) made by the leader.

The **braking space**, b_s, is given by:

$$b_s = \frac{v_n^2 - v_{(n-1)}^2}{2 \cdot d_n}, \tag{2}$$

where:

- v_n = current speed of vehicle *n* (follower),
- $v_{(n-1)}$ = current speed of vehicle *n-1* (leader),
- d_n = deceleration of vehicle *n*, given by Equation (6).

The **leader advancement**, $\Delta x_{(n-1)}$, quantifies the distance covered by the leader vehicle while the follower is braking. It is given by:

$$\Delta x_{(n-1)} = \frac{v_{(n-1)} \cdot \left(v_n - v_{(n-1)}\right)}{d_n}, \tag{3}$$

with v_n, $v_{(n-1)}$ and d_n as in (2).

A **stochastic following distance**, $S_{d,n}$, is assigned to each vehicle *n* in the model. Stochastic distances are assumed uniformly distributed between $(0.9 \cdot D_{d,n})$ and $(1.1 \cdot D_{d,n})$, with $D_{d,n}$, defined by Equation (4).

The **deterministic following distance,** $D_{d,n}$, is given by an empirical law proposed by Dijker, Bovy and Vermijs (1998):

$$D_{d,n} = \alpha_n + \beta_n \cdot v_{n-1} + \gamma_n \cdot v^2_{n-1}, \tag{4}$$

where:

- v_{n-1} = speed of vehicle *n-1* (leader),
- α_n, β_n, γ_n = parameters for vehicle *n* (follower).

Parameters α_n, β_n, γ_n vary with vehicle type (i.e., car or heavy vehicle), lane (right or left) and flow regime (congested or non-congested) and need to be specified as input by the model user based on local measurements.

When in the **conscious braking mode**, the driver reduces his speed by applying a **deceleration**, d_n. The model assumes a direct linear relationship between deceleration and speed difference between a follower vehicle and its leader.

$$d_n = d_{min} + \frac{d_{MAX} - d_{\min}}{v_{MAX} - v_{\min}} \cdot \left(v_n - v_{(n-1)}\right), \tag{5}$$

where:

- d_{min} = minimum deceleration,
- d_{MAX} = maximum deceleration,
- v_n = current speed of vehicle *n* (follower),
- $v_{(n-1)}$ = current speed of vehicle *n-1* (leader),
- v_{min} = minimum desired speed on the link,
- v_{MAX} = maximum desired speed on the link.

The model assumes a constant deceleration in each time step, and included between –1.5 m/s^2 and –2.5 m/s^2 (Schulze and Fliess 1997). If the leader vehicle changes its speed, the follower changes its deceleration accordingly. In particular, if the leader changes lane, the follower stops braking and starts accelerating (**conscious accelerating mode**).

When the speed difference between the leader and the follower is zero, the follower leaves the conscious braking mode to enter the following mode.

In the **following mode** the driver follows his leader, trying to keep the speed difference of the two vehicles equal to zero. However, due to imperfect throttle control and imperfect estimation of distance, the speed difference oscillates around zero and the driver unconsciously decelerates/accelerates (Fellendorf and Vortisch 2001). As in the free driving mode, the model assumes a normal distribution for the unconscious acceleration/deceleration, with average equal to zero and standard deviation equal to ¼ of the maximum acceleration/deceleration. Bounds are fixed in order not to overcome the maximum acceleration/deceleration (assumed to be ±2.5 m/s^2).

2.6 Lane-Changing

Lane changes are governed by a set of rules, taking into account both deterministic and stochastic psycho-physical aspects. In the model a lane change takes place when the leader vehicle is slower than the following vehicle. A generic vehicle *n* can move to the **lane-changing mode** in three cases:

1. While in the free driving mode, the driver perceives a slower vehicle ahead and changes lane without braking;
2. While in the conscious braking mode, the driver stops braking and changes lane at a speed $v_n < v_{d,n}$.
3. While in the following mode, the driver changes lane at a speed $v_n \cong v_{(n-1)}$ (v_n is generally slightly different from $v_{(n-1)}$ due to imperfect throttle control, see above).

In all cases the model assumes a transversal speed equal to 1.0 m/s.

As suggested by Zhang, Owen and Clark (1998), drivers do not change lanes any time they can. Some drivers tend to stay in one lane even when a lane change would let them increase their speed.

As a consequence, the model assigns each vehicle *n* an **overtaking factor**, OF_n, to eliminate the over-frequent lane changes and unrealistic effects as the *cooperative ping-pong effect* (Rickert et al. 1996). Only vehicles with an overtaking factor greater than a predefined threshold value, *TV*, will try to overtake slower leaders. Different threshold values can be specified as input for cars and heavy vehicles. OF_n is related to the vehicle's desired speed by means of the following equation:

$$OF_n = \frac{v_{d,n} - v_{min}}{v_{MAX} - v_{min}},$$

where:

- $v_{d,n}$ = desired speed of vehicle *n*,
- v_{MAX} and v_{min} as in Equation (5).

If $OF_n > TV$, the driver of vehicle *n* checks whether he can improve his present situation by changing lane. An improvement is determined by two alternative conditions:

$$v_{fl} > v_{cl}$$

or

$$v_{fl} \le v_{cl} \textbf{ AND } x_{fl} > x_{cl} + \Delta,$$

where:

- v_{fl} = speed of future leader, i.e. the vehicle ahead in the target lane,
- v_{cl} = speed of current leader,
- x_{fl} = position of future leader,
- x_{cl} = position of current leader,
- Δ = minimum distance headway that invites the driver to overtake. The model assumes a default value of 50 m for Δ.

If one of the two conditions mentioned above is met, the driver checks whether he can change lane without generating a dangerous situation in the left lane. For this purpose, a **gap acceptance procedure** has been implemented, taking into account the future leader's and future follower's speeds and positions. Vehicle *n* changes lane only if the two following conditions are simultaneously met:

$$\begin{aligned} &a)\ (x_{fl} - x_n) > FG_{min} \\ &b)\ (x_n - x_{ff}) > BG_{min} \end{aligned} \tag{6}$$

where:

- x_n = current position of vehicle *n*,
- x_{fl} = current position of future leader,
- x_{ff} = current position of future follower,
- FG_{min} = minimum forward gap,
- BG_{min} = minimum backward gap.

Minimum gaps are calculated taking into account vehicles' braking distances, stochastic headway distances and lengths, using expressions similar to Equation (1).

The lane-changing manoeuvre of vehicle n can force the future follower to brake (**conscious braking mode**) should the distance between the two vehicles fall below the future follower's critical gap defined by Equation (1).

As soon as the lane-changing manoeuvre starts, vehicle n's driver increases his own speed (**conscious accelerating mode**) until he reaches his desired speed or a slower vehicle downstream forces him to decelerate. The vehicles' acceleration is assumed to be between 1.5 m/s^2 and 2.5 m/s^2.

The overtaking manoeuvre is complete when:

$$v_n = v_{d,n} \textbf{ AND } x_n > (x_{(n-1)} + BG_{min}) \text{ if k=1} \qquad (7)$$

or

$$v_n = v_{d,n} \textbf{ AND } x_n > (x_{(n-k)} + BG_{min}) \text{ if k>1,}$$

where:

- v_n = current speed of vehicle n,
- $v_{d,n}$ = desired speed of vehicle n,
- x_n = current position of vehicle n,
- $x_{(n-1)}$ = current position of vehicle $n-1$ (previous leader),
- $x_{(n-k)}$ = current position of vehicle $n-k$ (platoon leader),
- k = number of vehicles in the platoon,
- BG_{min} = minimum backward gap.

The second condition in (7) takes into account the possibility that vehicle $n-1$ (vehicle n's leader prior to the lane changing) belongs to a platoon of k vehicles, as shown in Figure 3.

When the overtake is complete, vehicle n can move back to the right lane (**lane-changing mode**), provided that it does not create a dangerous situation in doing so. The possibility of changing lane is subject to simultaneous satisfaction of the two conditions expressed by the (6).

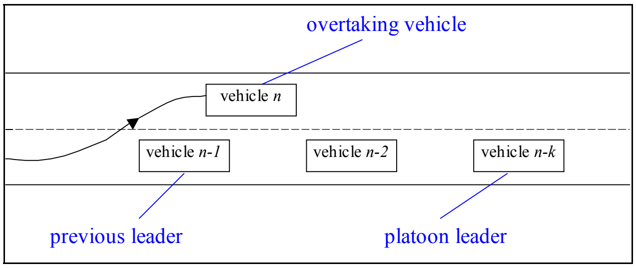

Figure 3: The Overtaking Manoeuvre

When back in the right lane, vehicle n can drive at its desired speed (**free driving mode**) as far as it meets a slower vehicle ahead.

A specific rule has been implemented to avoid unrealistic weaving movements of vehicles. The rule sets a minimum time interval between two consecutive overtaking manoeuvres by the same vehicle. The default value for the time interval is 15 seconds.

3 THE MODEL OUTPUTS

Model outputs are automatically written and stored in two output files.

The first file, *motion.txt*, keeps records of each vehicle's actions during each simulation run. For each individual vehicle, the model provides the following data every 0.1 second:

- Current time (i.e., current value of the simulator's clock);
- Vehicle ID (an integer attached to each individual vehicle);
- ID of the leader vehicle, i.e., the ID of the nearest vehicle ahead in the same lane;
- Vehicle type (small car, large car, bus or truck);
- Vehicle color (white, yellow, orange or red);
- Lane (1-right lane, 2-left lane);
- Current position, measured from the beginning of the link;
- Previous speed, i.e., the vehicle's speed stored in the previous time step;
- Current speed, i.e., the vehicle's speed in the current time step;
- Desired speed (see section 2.4);
- Acceleration (deceleration if negative);
- Accelerating, a Boolean variable showing whether the vehicle is accelerating; imperfect throttle control and imperfect estimation of distance can cause an unconscious acceleration (see section 2.5);
- Braking, a Boolean variable showing whether the vehicle is braking; as for the acceleration, imperfect throttle control and imperfect estimation of distance are often the cause of an unconscious deceleration;
- Lane changing, a Boolean variable showing whether the vehicle is shifting from one lane to the other;
- Following, a Boolean variable showing whether the vehicle is in the car-following mode;
- Free driving, a Boolean variable showing whether the vehicle is in the free driving mode.

The second file, *longlink.rtf*, reports information about random variables. Five random variables have been chosen to synthesize vehicles' movement on the road section:

- the **running time**, i.e., the effective time required to travel on the studied road section,

- the **lost time**, i.e., the extra time required to travel on the road section in excess of the travel time at the individually desired speed (Showers and Courage 1998),
- the **macroscopic flow**, i.e., the number of vehicles per hour driving through the studied road section,
- the **macroscopic density**, i.e., the number of vehicles per km in the studied road section,
- the **macroscopic speed**, i.e., the average speed of vehicles driving through the studied road section.

As for the three macroscopic variables, the model calculates their values every minute. The model user has the possibility to change the default time step.

Further random variables will be soon introduced to quantify vehicular consumption and emissions.

The *longlink.rtf* file reports the number of times each random variable has been observed (**#Obs**), its average value (**Mean**), its standard deviation (**St Dev**), and its minimum (**Min**) and maximum (**Max**) values. Table 2 gives sample values for running time and lost time (in seconds), and macroscopic flow (in vehicles per hour), density (in vehicles per km) and speed (in m/s).

The model observes random variables in the steady state of the traffic system only. The influence of the transient phase (**warm-up period**) is rejected (Schulze and Fliess 1997).

Table 2: Random Variables Evaluated through Microsimulation

Variable	#Obs	Mean	St Dev	Min	Max
runningTime	479	19.42	4.05	13.30	25.30
lostTime	479	1.64	2.11	0.00	7.14
macroFlow	14	1932.86	187.06	1620.00	2220.00
macroDensity	14	25.64	2.41	22.00	29.00
macroSpeed	14	25.43	0.94	24.00	27.00

The steady-period duration is specified as input by the model user, while the warm-up-period duration, *WU*, is related to link length and minimum desired speed on the link by means of the following:

$$WU = \frac{link}{v_{\min}},$$

with: $v_{min} = \min \{v_{min,1}, v_{min,2}\}$,

where:

- $link$ = link length,
- v_{min} = minimum desired speed,
- $v_{min,1}$ = minimum desired speed on the right lane,
- $v_{min,2}$ = minimum desired speed on the left lane.

4 THE ANIMATION

The microsimulation model automatically writes a layout file (*longlink.lay*) and a trace file (*longlink.atf*) at each simulation run. Such files can be used by Proof Animation (Henriksen 2000b, Earle et al. 1995), a vector-based, file-driven, post-processing animation system.

The first file provides Proof Animation with geometric data about the vehicles (length and width) and the link (length and width of each lane), together with information about the dynamic indicators, bars and plots to be displayed during the animation. A specific SLX-code has been developed by the author in order to automatically write Proof Animation layout files.

The second file provides Proof Animation with a list of commands about actions to be executed during the animation (e.g., creation and destruction of objects, speed and color changes). A trace file is automatically created by any SLX-based simulator.

Six dynamic indicators have been selected to synthesize traffic flow behavior on the selected road section (see Figure 4):

- The number of vehicles currently driving in the right lane (*Vehicles in the right lane*);
- The number of vehicles currently driving in the left lane (*Vehicles in the left lane*);
- Vehicles currently driving in the car-following mode (*Vehicles in car-following*);
- The total number of vehicles that have passed through the selected section since the animation started (*total vehicles passed*);
- The total number of vehicles that have shifted from the right to the left lane since the animation started (*total lane changes*);
- The total number of vehicles that have shifted from the left to the right lane since the animation started (*total re-enters*).

Dynamic bars are attached to the first three indicators, as shown in Figure 4. Dynamic plots show changes for macroscopic flow, density and speed during the steady period (see Figure 4).

Vehicles are assigned one of four colors, ranging from white to red, based on the vehicle's desired speed. A darker color means an higher desired speed. An SLX procedure has been developed to set the color and pass this information to Proof Animation.

Figure 4: Snapshot of the Animation

Vehicles in the car-following mode are identified by a small green flag attached to the vehicle when its movement is affected by a slower leader (see Figure 5). The flag remains attached to a vehicle until it leaves the car-following mode (e.g., by means of a lane change).

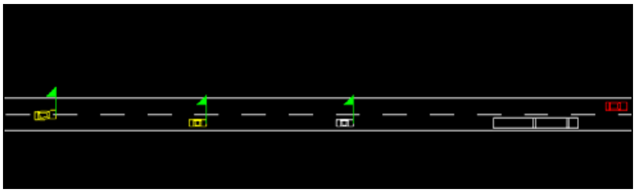

Figure 5: Flagged Vehicles in Following Mode

Finally, the passage of time is represented by the icon of a small clock on the right of the screen, as illustrated in Figure 4.

5 THE USER INTERFACE

A user-friendly interface has been developed using Microsoft Visual Basic. When the model is launched a 7-tab dialog window appears (see Figure 6).

Each tab needs to be sequentially filled in with input data. Error message boxes (see Figure 6) signal any missing values prior to proceeding to the next tab. Default inputs are provided to the model user for initial testing by clicking the "*Set default parameters*" button.

Input data are automatically written and stored in a text file (*inputs.txt*) that is read by SLX. Clicking on the "*Run SLX*" button starts the simulation. After the simulation is run, the model user can choose to view the animation by simply clicking on the "*Animation*" button.

Finally, the "*Outputs*" button indicates the directory where the output files *motion.txt* and *longlink.rtf* (see section 3) are stored.

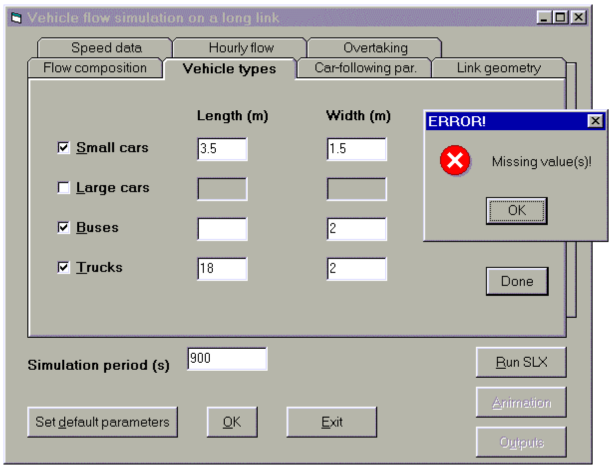

Figure 6: The User Interface

The tabbed dialog window is a simple, compact and easy-to-use platform by which the model user can control the whole simulation process without having to enter and modify the SLX code or the text files.

6 CONCLUSIONS

The paper presents a car-following and lane-changing microsimulation model of a two-lane road section written in SLX. The two-lane road model is the first component of a larger model aiming at microscopically simulating vehicle flows on an urban road network. For this purpose, several additional components will be analyzed and simulated: multi-lane roads, signalized and unsignalized intersections, roundabouts.

The key element of the next phase will be microsimulation of a signalized intersection. Procedures to simulate and animate vehicle arrivals, queues and departures will be developed.

Finally, the microsimulation components will be linked and used to reconstruct vehicle driving cycles. Microsimulation will be based on outputs from a traditional transport macroscopic model (traffic flows and speeds) and will provide inputs (the driving cycles) to an ultra-micro model that will calculate consumption and emissions of all the vehicles in the network.

The macro-, micro- and ultra-micro models will be calibrated and validated on the Rome city road network.

REFERENCES

Aycin, M. F. and R. F. Benekohal. 1998. A Linear Acceleration Car-Following Model Development and Validation. In *Preprint CD-ROM of the 77th TRB Annual Meeting*. Washington, D.C.

Ben-Akiva, M. E., H. N. Koutsopoulos, R.G. Mishalani, and K.I. Ahmed. 1995. Modeling Freeway Lane

Changing Behavior. In *Proceedings of the Applications of Advanced Technologies in Transportation Conference*. ASCE, Capri.

Dijker, T., P. Bovy, and R. Vermijs. 1998. Car-following under congested conditions: empirical findings. In *Preprint CD-ROM of the 77th TRB Annual Meeting*. Washington, D.C.

Earle, N., J. Lopacki, E. Tucker and J. O. Henriksen. 1995. *Using Proof Animation*, 2d ed. Annandale, VA: Wolverine Software Corporation.

Fellendorf, M. and P. Vortisch. 2001. Validation of the Microscopic Traffic Flow Model VISSIM in Different Real-World Situations. In *Preprint CD-ROM of the 80th TRB Annual Meeting*. Washington, D.C.

Gipps, P. G. 1981. A behavioral car following model for computer simulation. *Transportation Research B*, 15B, 105–111.

Gipps, P. G. 1986. A model for the structure of lane-changing decisions. *Transportation Research B*, 20B, 403–414.

Henriksen, J. O. 2000a. SLX: The X is for Extensibility. In *Proceedings of the 2000 Winter Simulation Conference*, ed. J. A. Joines, R. R. Barton, K. Kang, and P. A. Fishwick, 183–190. Available online via `<http://www.informs-cs.org/wsc00papers/027.PDF>` [accessed March 19, 2001].

Henriksen, J. O. 2000b. Adding Animation to a Simulation Using Proof™. In *Proceedings of the 2000 Winter Simulation Conference*, ed. J. A. Joines, R. R. Barton, K. Kang, and P. A. Fishwick, 191–196. Available online via `<http://www.informs-cs.org/wsc00papers/028.PDF>` [accessed March 19, 2001].

Nagel, K., P. Stretz, M. Pieck, S. Leckey, R. Donnelly and C. L. Barrett. 1999. TRANSIMS traffic flow characteristics. Los Alamos Unclassified Report (LA-UR) 97-3531, Los Alamos National Laboratory, New Mexico. Available online via `<http://www.inf.ethz.ch/~nagel/papers/flow-char/flow-char.pdf>` [accessed March 28, 2001].

Rickert, M., K. Nagel, M. Schreckenberg, A. Latour. 1996. Two lane traffic simulations using Cellular Automata. *Physica A* 231: 534–550.

Schulze, T. and T. Fliess. 1997. Urban traffic simulation with psycho-physical vehicle-following models. In *Proceedings of the 1997 Winter Simulation Conference*, ed. S. Andradóttir, K. J. Healy, D. H. Withers, and B. L. Nelson, 1222–1229. Available online via `<http://www.informs-cs.org/wsc97papers/1222.PDF>` [accessed March 19, 2001].

Showers, R. H., and K. G. Courage. 1998. CORSIM treatment of gap acceptance and delay. *Preprint CD-ROM of the 77th TRB Annual Meeting*. Washington, D.C.

Zhang, Y., L. E. Owen and J. E. Clark. 1998. A multi-regime approach for microscopic traffic simulation. *Preprint CD-ROM of the 77th TRB Annual Meeting*. Washington, D.C.

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