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Parametrization of microscopic Traffic Flow Models through Image Processing

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PARAMETRIZATION OF MICROSCOPIC TRAFFIC FLOW MODELS THROUGH IMAGE PROCESSING

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Abstract: Some decisions of urban traffic control are based on microscopic traffic flow simulation models. In each application parameters describing locally observed driving behaviour as well as parameters setting up the network have to be adjusted. To reduce the effort needed for calibration and validation this study deals with a parametrization method through image processing. Within the study one image processing system is applied to calibrate parameters of the microscopic traffic flow model of WIEDEMANN. A Simulated Annealing Algorithm is used to match observed and simulated values. Results of the calibration process are outlined using a partially signalized roundabout.

Keywords**:** Distributed detection, Driver models, Heuristic searches, Image Processing, Modelling, Optimization problems, Parametrization, Traffic control, Validation

1. INTRODUCTION

Computers with continually rising performance along with improved software tools allow to model complex urban city traffic situations for practical applications. The possibility of realistic animation of single vehicles on computer display gives the impression of high model accuracy. The modelling has to take this expectation into account.

Urban traffic models require numerous parameters to describe the traffic flow in detail. Local conditions such as lane allocation, relations of origin-destination and general information such as driver behaviour have to be provided in traffic flow models as input parameters. It requires a rather large amount of effort to determine these parameters for each application manually. Without comprehensive work devoted to the adjustment of the input parameters microscopic traffic flow models are likely to produce non realistic results. Calibration of the input parameters of traffic flow models is of crucial importance to validate such simulation models. Therefore the authors study the possibilities to improve the current methods to calibrate microscopic traffic flow models.
Within this study methods of automated parametrization and validation of traffic flow models through image processing are considered. The project intends to reduce the cost to adjust microscopic traffic flow models as well as to improve their accuracy. A widely used image processing system should be applied. The parametrization and validation should be possible for parameters of various traffic flow models but one should be chosen as example. In particular the method should be suited to calibrate the parameters required by the psycho-physical traffic flow model of WIEDEMANN (Wiedemann, 1974), which is applied in numerous simulation studies throughout Germany.

The general objective requires that those traffic flow data gets recorded and analyzed by image processing system which is most suited to calibrate the traffic flow model. Secondly suitable algorithms have to be found to calibrate the traffic flow model with traffic measurements.

2. IMAGE PROCESSING SYSTEM

Recording of traffic by video and the following determination of interesting model parameters by an image processing system avoids to interrupt the road traffic. The placement of weatherprotected camcorders should meet several requirements. In order that traffic observation don't affect the driver behaviour inconspicuous places should be chosen. A camcorder position as high as possible allows to observe a wide area at nearly vertical view axis required and thus reduces mutual overlapping of vehicles. The practice has shown that an advantageous placement of camcorders considerably reduces the effort for fault detection and fault elimination through image processing after recording.

Image sensing systems allow to place and alter several virtual detector loops on the screen for further analysis of the traffic. Vehicle types, velocity and occupancy rates can be detected. Several camcorders are necessary to record various movements on complex junctions. However, camcorders are relatively inexpensive and one camera can substitute several traditional detector loops.

As most image processing systems currently available commercially AUTOSCOPE 2004 (Image Sensing Systems, Inc.) is used for detection of directional traffic on motorways. An evaluation of different modern traffic detector technologies for IVHS applications is given in (Klein and Mills, 1994). The selected system achieved one of the best results regarding vehicle detection on various lighting conditions and met the requirements of the study by particular features as (1) elimination of shadows and headlight reflections, (2) number of virtual detectors up to 99, (3) different detector types specialized in counting, speed measurement, presence detection etc., and (4) collection of interval and single event data. During detection the system is writing a file, which contains the date, time and length of time the detector remained actuated. This file makes it possible to further improve the detection accuracy by off-line analysis. However, it should be noticed that the selected video vehicle detection system achieves the best results for IVHS applications. Several problems have to be solved for the analysis of traffic at urban junctions. For example detection faults are caused by mutual overlapping of vehicles. In order to eliminate these errors, the same traffic situation scene can be observed by two camcorders from different locations. The analysis requires the logical combination of detector events.

Another difficulty consists in common occupancy of virtual detectors by differently directed traffic flows. In this case different detectors with each special function observe the same area of the junction. The area of interest is driven through by vehicles from different directions.

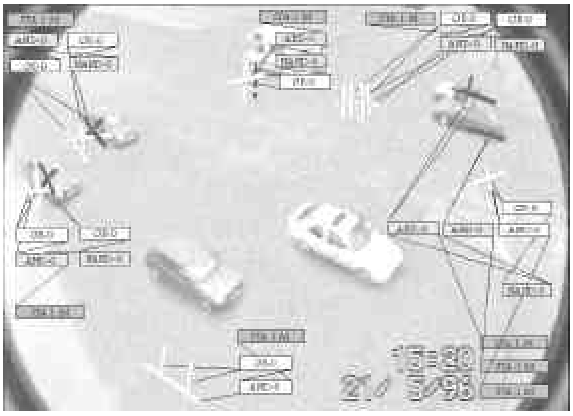

Fig. 1. Arrangement of virtual detectors

The direction sensitive detectors are sensitive for a relatively wide crossing angle. This behaviour leads to fault detection. Additional detectors can avoid fault signals. Further count detector is responsible for recognition of gaps between passing vehicles. The valid detection is combined from signals of specialized detectors. Figure 1 shows a traffic scene with overlaid virtual detectors.

Furthermore the video tapes with widely distributed traffic scenes have to be sequentially handled. An off-line statistical data analysis allows to reduce the error rate. It should be noted, that the local video observation of traffic flows provides only such parameters as traffic volume on several lanes, rates of turning vehicles, rates of heavy traffic, distribution of actual speeds, and the distribution of vehicle lengths.

The network model is reflected by O/D relations whose estimation is not yet supported by the applied image processing system. The tracing of every vehicle over a wide distance from a fixed point does not seem to be practical yet because of two reasons: First, the limited height of camcorder position leads to mutual overlapping of vehicles at the screen. Second, an image processing system is still unknown, which is able to separate several vehicles from each other in real time. For these reasons image processing is only suited for local measurement, and the problem of estimation of O/D relations still remains.

3. MICROSCOPIC TRAFFIC FLOW MODEL

The traffic flow model used in this study is a discret, stochastic, time step based (1s) microscopic model, with driver-vehicle-units (DVU) as single entities. The model contains a psycho-physical car following model for longitudinal vehicle movement and a rule-based algorithm for lateral movements. The model is based on the continuous work of WIEDEMANN (Wiedemann, 1974 and 1991) and is implemented in a software package called VISSIM (Fellendorf, 1994), which is used within this study.

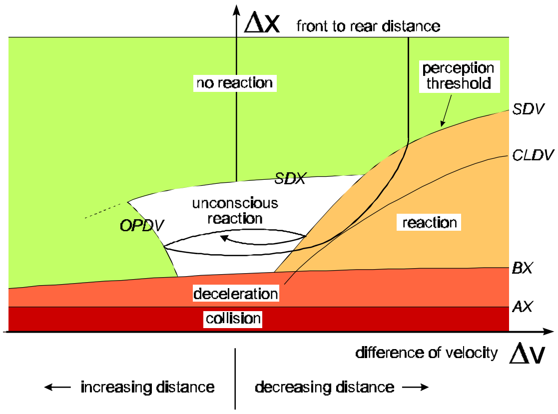

Fig. 2. Car-following model of WIEDEMANN Thresholds and one vehicle trajectory

As a faster vehicle approaches a slower vehicle on a single lane it has to decelerate. The action point of conscious reaction depends on the speed difference, distance and driver depended behaviour. Figure 2 indicates the oscillating process of this approach.
The thresholds of figure 2 are explained in an abbreviated form. Driver specific perception abilities and individual risk behaviour is modelled by adding random values to each of the parameters as shown for AX. For a complete listing of the random values the reader is referred to (Wiedemann and Reiter, 1992).

AX: Desired distance between the fronts of two successive vehicles in a standing queue.
$AX := VehL + MinGap + RND1 \cdot AXMult$
with RND1 normally distributed N(0.5, 0.15)

ABX: Desired minimum following distance which is a function of AX, a safety delta distance BX and the speed
$ABX := AX + BX \cdot \quad v$

SDV: Action point where a driver consciously observes that he approaches a slower car in front. SDV increases with increasing speed differences (*Dv*). In the original work of WIEDEMANN an additional threshold cldv (closing delta velocity) is applied to model additional deceleration by usage of the brakes with a larger variation than SDV.

OPDV: Action point where the following driver notices that he is slower than the leading vehicle and starts to accelerate again. The variation of OPDV is large (Todsiev, 1963).

SDX: Perception threshold to model the maximum following distance which is about 1.5 - 2.5 times ABX.

A following driver reacts to a leading vehicle on up to a certain distance which is about 150 m. The minimum acceleration and deceleration rate is set to be 0.2 m/s². Maximum rates of acceleration depend on technical features of vehicles which are usually lower for trucks than the personal desire of its driver. The model includes a rule for exceeding the maximum deceleration rate in case of emergency. This happens if ABX is exceeded. The values of the thresholds depend on the present speed of the vehicle. Figure 3 denotes the values for two different speeds to display a current set of values.

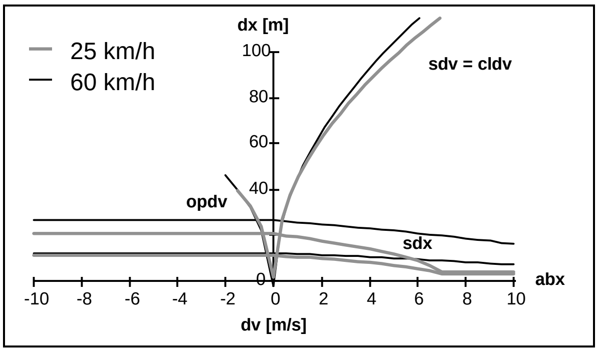

Fig. 3. Car-following thresholds used in urban situations as a function of the speed

In case of multi-lane roads a hierarchical set of rules is used to model lane changes. A driver has a desire to change lane if he has to drive slower than his desired speed due to a slow leading vehicle or in case of an upcoming junction with a special turning lane. Then the driver checks whether he improves his present situation by changing lanes. Last he checks whether he can change without generating a dangerous situation. In case of multi-lane approaches towards intersections this method will lead to evenly used lanes unless routing information forces vehicles to keep lanes.

4. CALIBRATION AND VALIDATION

The results of the simulation are compared with measurable traffic data. Simulation parameters which can not be measured directly by traffic observation have to be adjusted according to validation values. Those parameters are denoted as *calibration* parameters. *Validation* values are measurable not having an equivalent calibration parameter. The calibration of the longitudinal and lateral model is a complex problem because of numerous interdependencies of its parameters. For example: The discharge rate at a signalized intersection as the green period begins, depends on local conditions regarding (1) start accelerations, (2) distances between vehicles in a queue, (3) the length of queues, and (4) the car following behaviour. The validation value measured will be saturation flow and discharge rates if vehicle positions within the queue are considered. The maximum used acceleration rate at the stop line BMax is a non measurable calibration parameter of the car-following model. Depending on the value of BMax the saturation flow will vary between 1.200 veh/h*lane (3.0 s/veh) and 2.200 veh/h*lane (1,64 veh/s) (Figure 4).

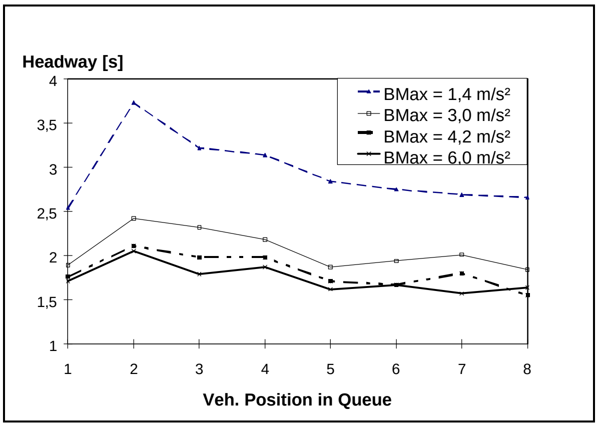

Fig. 4. Discharge rate as a validation parameter

There are numerous additional parameters to calibrate the car-following and the lane changing model. Furthermore other traffic data like origin-destination values have to be calibrated by applying the traffic flow model for complex junctions or even networks.

Parameters which can be measured automatically and thus being applied for adjustment of input parameters and validation directly are:

- volumes over time,
- traffic composition (truck rates),
- speed distribution, and
- discharge rate at traffic lights (saturation flow).

Calibration parameters which can not be observed through automatic image processing yet:

- distribution of desired speeds with respect to speed limits and geometry of junctions,
- start accelerations,
- distribution of distances between vehicles in a stopped queue,
- threshold values of the car-following model of WIEDEMANN as shown in figure 2 and
- gap acceptance at priority junctions.

5. ALGORITHM FOR CALIBRATION

The calibration algorithm is formulated as an optimization problem, which is solved by a selective algorithm. In this study among others a method called Simulated Annealing (Vidal, 1993) is used.

Selective algorithms based on simple search for local minima. One after the other for parameter sets denoted by vector $\mathbf{x}^i$ a cost function $c(\mathbf{x}^i)$ is calculated. Here the parameters are randomly varied within a given range. If the new value of $c(\mathbf{x}^j)$ is less than the old value of $c(\mathbf{x}^i)$ then the old parameter set is rejected. This rigid condition allows to find local minima only. The way out from this dilemma consists in introduction of a probability of acceptance, which avoids the hard rejection of less proper parameters first. This strategy is similar to tolerating a temporary risk in order to get the best position in a game.

Figure 5 depicts the Simulated Annealing Algorithm in general form used for experiments. Here $\mathbf{z}_S$ denotes a vector of random numbers [-1, 1], *a* influences the step width, and *e* denotes the termination bound. The probability of acceptance is introduced by a monotonous decreasing sequence of control parameter $\{T_k\}^l_{k=0.}$ Decreasing values of $\{T_k\}^l_{k=0}$ reduce the acceptance probability of parameter sets with unfavourable values of suitable normalized cost function. With increasing *k* the chance decreases, that term $exp(\Delta c(\mathbf{x}^i,\mathbf{x}^j)/T_k)$ is greater than random number *p* [0,1).

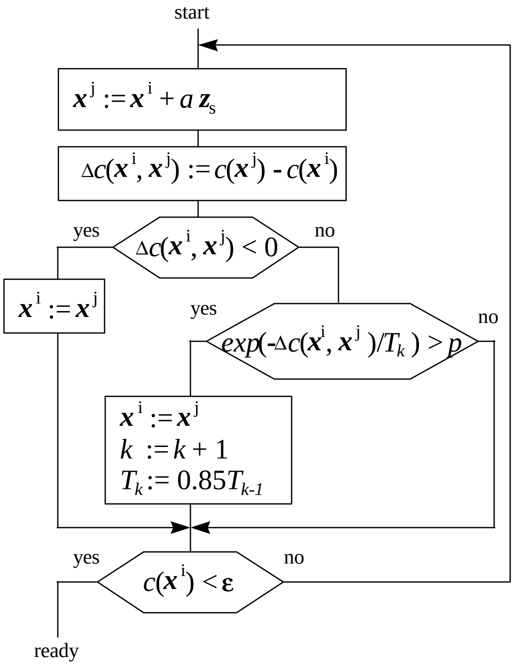

Fig. 5. Simulated Annealing Algorithm

The calibration process may be outlined as follows (see Figure 6):

1. The image processing system provides measurable parameters for the network model (e.g. traffic volumes adjusted at the cordon, rates of turning vehicles).
2. The remaining parameters of the car following model are set up as standard values from previous runs, and the simulation run is started.
3. A set of validation quantities simulated (e.g. flow rates, measured between intersections) is compared with a set of quantities measured by image processing system.
4. Based on the observed differences of the validation quantities the parameter set of the traffic flow model is altered automatically considering also previous simulation runs. The aim of the additional simulation run is to lower the deviation between simulated and measured quantities.
5. As soon as threshold criteria are reached, the simulation runs terminates.

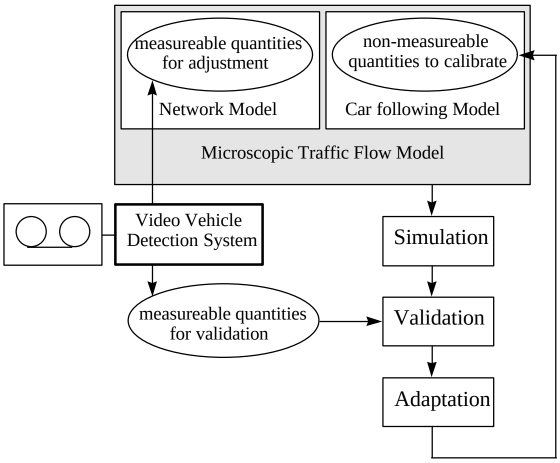

Fig. 6. Procedure of calibration

6. EXAMPLE

An example of practical background will be explained in this section. The results of model calibration through Simulated Annealing achieved by simulation experiments are documented briefly.

Figure 7 shows a snapshot of the simulation model topology and its traffic situation at a certain point of time. The multi-lane roundabout has four approaches and exits with two lanes each. Trams are crossing the roundabout from north to south and from south to east. Vehicle actuated signal control at the south entrance will guarantee full tram pre-emption in most cases. The remaining approaches are non signalized. Priority is given to the vehicles travelling in the roundabout against the vehicles on the approach.

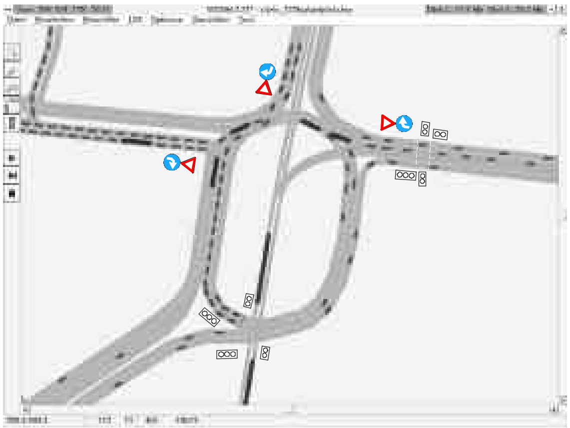

Fig. 7. Simulation model topology of the example

A simulation study should answer the question, how often an additional green stage for pedestrians crossing the eastern exit will cause queues within the roundabout during peak periods. Queues all down to the southern entrance are most unwanted since the tram priority is not valid in those cases. Additionally the impact of trams on individual traffic had to be investigated.

Setting up the network and relevant traffic data is quickly done as compared with finding a proper parametrization of the situation. The validation of first simulation runs resulted in considerable differences between observed and simulated traffic flows. These differences particularly concerned position and length of queues as well as lane usage. For the evaluation of model validity the flow rates of several lanes within the roundabout were measured. The O/D relations were known. First attempts to manually adjust proper parameters in order to reduce the faults were inefficient and caused high investigation costs. For this reason an automated calibration procedure has been required. The method described above was applied to the example. For 16 simulated flow rates of all approaches and exits q^{i}_{sim} was compared with real values recorded on video tapes q^{i}_{real}. At first sight the flow rates at stop lines in front of the circus are equal the generation rates of vehicles at the model boundaries, but concerning mean values over short intervals the dynamic of congestion forming must be taken into consideration. That means increasing congestions reduce flows , and decreasing congestions increase flows, respectively. It should be mentioned that initial conditions of the simulated term have to be absolutely noted.

In order to simplify the first steps of development, the quantity of adjustable parameters was limited to gaps of time and distance in the traffic flow with right of way. The direct determination of latter through image processing causes a great effort for placement of virtual detector loops and logical combination of their events. Moreover the accuracy is relatively coarse. Therefore the spatial distance was assumed as non measurable parameter and was fixed.

The variance of observed gaps is relatively wide. They essentially depend on the behaviour of drivers being between politeness and recklessness.
The cost function applied to search for the best validity is given by

$$c(\mathbf{x}^{\mathbf{i}}) = \left[\max_i \frac{q^i_{sim} - q^i_{real}}{q^i_{real}} \right] \rightarrow \min \qquad (1)$$

The evaluation of successfully setting the parameters by Min-Max criterion corresponds to pessimistic view, that means the model validity could be better than simulation result shows. In contrast to this evaluation by an average criterion could lead to an optimistic assessment of model validity. The application of the Simulated Annealing Algorithm to the example improved the maximum initial deviation from 0.287 to 0.118 after 321 simulation runs. Here the initial control parameter T_0 amounted to 100. Further results will be presented on the symposium.

7. CONCLUSIONS

A method of improving microscopic traffic flow models by image processing has been shown. A commercially available image processing system analyzes video records and provides quantities for parametrization of the model in reasonable time. Image processing systems are of great help for calibration since many traffic situations can be analyzed.
The approach of calibration is based on an algorithm of Simulated Annealing which efficiently chooses the most promising parameters for a good validity of the model. First practical tests of the algorithm show that improvements can be made by calibration of certain traffic flow parameters automatically.

Further research will be focused on variation of larger parameter sets. It will be investigated, whether other approaches can efficiently handle numerous parameters caused by more extensive sets and application of the model in more complex network situations.

8. ACKNOWLEDGEMENTS

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