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Route Choice Model for Online Microscopic Simulation

Marc Ph. Miska, Theo H. J. Muller, Henk J. van Zuylen

Abstract—Online microscopic simulation is very sensitive to driving behavior of the individual vehicle-driver combination. Therefore a virtual driver module has been developed, which includes a route choice model to assign traffic flows between the origin and destination under real-time conditions. The route choice model presented in this paper assigns vehicles in a non-iterative way based on the view of the individual driver. Additionally, it allows to model the influence of en route information and individual in car routing equipment.

Index Terms—microscopic, online, real-time, route choice, simulation.

I. INTRODUCTION

Due to the fact that online simulations are very sensitive to the driving behavior of the individual vehicle-driver combinations, a virtual driver module for microscopic simulation has been developed. This has been included into a microscopic online simulation model for the “Region Laboratory Delft”. The aim of this project is to support traffic managers of different road authorities with online data of the actual traffic situation and a prediction with a rolling horizon of about 30 minutes ahead.

The route choice model described in this paper is part of that module. It allows a non-iterative dynamic assignment of traffic flows in real-time simulation. Vehicles are assigned to the shortest route in the empty network and the comfort of the driver determines, when and if the driver considers to switch to another route. To calibrate the model, the threshold for feeling comfortable and the recommendation of some specific link types are used. In this way it is prevented that long trip vehicles will choose a route through a city center and on the other hand drivers are forced to take an earlier off-ramp of a city if this gains

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time. Route guidance systems and en route information (dynamic route information panels) are also included and implemented in this factor.

Tests on artificial and real networks have been done and shown that the approach delivers accurate and expected results. Additional, it will be shown, that the travel-time distribution in congested traffic situation, using this model, has a very low bandwidth.

II. FRAMEWORK

A. Region Laboratory Delft

The “Region Laboratory Delft” (a combined research institute of the Technical University Delft, the Ministry of Transport, road authorities and industry) collects on line data about the use of the infrastructure in the region of Delft [4]. In addition, it also receives information about the actual status of the traffic control systems (ramp metering, speed control, lane use), weather conditions, and so on.

The collected data are processed into meaningful information for traffic management (on-line), research and education (off-line). Traffic managers of different road authorities are informed about the actual traffic operations influenced by traffic control measures in an extensive common road network of all road authorities. The data are used to feed a microscopic online simulation model that predicts short term road use.

B. Microscopic Online Simulator

The microscopic online simulator (MiOS) [2] distinguishes two major parts. The first part is the *estimation* of the actual traffic situation, based on the real-time data. Measurement points at the border of the model are used as sources for the vehicle input and output. Other points are used to verify and calibrate real-time estimation by means of microscopic simulation. An agent based simulation method estimates online the turning relations, and the origin–destination flows.

The differences between the measurement and the simulation results are calculated and the simulation is corrected by attuning acceleration and deceleration of single cars or by changing the route choice for specific vehicles. This results in an ongoing microscopic view of the actual traffic situation of the urban network around the

city of Delft. The accuracy of the estimation is given by the calculated differences and is shown link based.

The second part *predicts* (by simulation) the traffic situation with a rolling horizon with a maximum of about 30 minutes. This simulation is based on actual traffic estimation (part one), driver behavior, and active control systems. A new prediction simulation is started every 5 to 10 minutes. Meanwhile, the estimation methods are applied using the former prediction to achieve an ongoing picture of the future situation.

The simulator is based on cellular automata [6], extended by a virtual driver module, which determines the view of a driver and his or her reaction on the situation. For the behavior, in this stage of the model, the car following model from Wiedeman [5] is used. Additionally, this extension provides interfaces for driving assistance equipment to include the effect of route guidance, intelligent speed adoption (ISA), or automatic driver assistance systems (ADAS) into the simulation results. To compensate the amount of computational power, the system is distributed in a computer network. In this way even large networks can be handled.

III. METHODS

A. Network Representation

The network is represented with a directed graph $G := (V;R)$, where V is the set of vertices and $R \subseteq V \times V$ is the set of ordered vertex pairs (edge set). The graph is antireflexive, asymmetric, cyclic and hence free of loops. The routes between origin o and destination d are represented by the set a_{od} containing paths between vertex o and d . The minimum of the length of the paths contained in a_{od} is chosen as the weight z_{od} of the path set a_{od} . If the path set a_{od} is the zero set 0_W , then $z_{od} = \infty$. If the path set a_{od} is the unit set 1_W , then $z_{od} = 0$. If the path set a_{od} is neither the zero set 0_W nor the unit set 1_W , then z_{od} is a non-negative real number. Thus, the weight mapping is defined as follows [1]:

$$\begin{aligned} \text{zero element : } 0_Z &= \infty \\ \text{unit element : } 1_Z &= 0 \\ \text{element : } z_{od} &\in \mathfrak{R}_0^+ \text{ for } a_{od} \notin \{0_W, 1_W\} \end{aligned} \quad (1)$$

B. Definition of Weights

The elementary weight matrix Z of the graph contains link based weights z_{ik} , which are determined by the length of the link l_{ik} from vertex i to vertex k , the actual average speed v_{ik} of V cars on that link, the maximum speed $v_{\max,ik}$ and the recommendation parameter θ :

$$z_{ik} = \frac{l_{ik}}{\sum_V v_{ik} + v_{\max}} * (V + 1) * \Theta \quad (2)$$

The parameter Θ distinguishes the different road types and takes in-car route guidance systems and en-route traffic information into account. Let:

- T: be the road type
- α : an indicator for in-car systems and
- β : be a factor for en-route information

Then Θ can be described as:

$$\Theta = (\alpha + \beta) * T \quad (3)$$

with:

$$\alpha := \begin{cases} 0 & \text{car is equipped} \\ 1 & \text{car is not equipped} \end{cases}$$

$$\beta := \begin{cases} 0 & \text{mandatory} \\]0,1[& \text{advice} \\ 1 & \text{none} \end{cases}$$

and:

$$T := \begin{cases} 1.0 & \text{for highways} \\ 2.5 & \text{for urban roads} \\ 5.0 & \text{for inner-city roads} \end{cases}$$

That means, that a driver never mind the type of the road if his or her navigation system advises a route or a mandatory redirection is given en route. For non equipped vehicles, the parameter β represents the willingness of the driver to follow en route information.

In this state of the project, the parameters for β and T , given above, are equal for all cars. Only a percentage of equipped cars is used as a further input. Due to the fact that MiOS is able to handle different network parts parallel, it has been chosen to fix the parameters for parts of the network. In a further step, this will be examined in more detailed.

C. Driver Perspective

When a vehicle is generated, it is assigned to the shortest route between its origin o and its destination d in an empty network. The driver is trying to find another the route if he does not feel comfortable anymore.

Let be:

- $v_{a,v}$ the actual speed of driver v
- $v_{d,v}$ the desired speed of driver v

$f_{r,v}$ the number of cars on edge r , where v is driving and
 $f_{r,\max}$ the maximum amount of vehicles for edge r .

Then the comfort factor c_v of driver v is determined as:

$$c_v = \frac{v_{a,v}}{v_{d,v}} - \frac{f_{r,v}}{f_{r,\max}} \quad (4)$$

Due to the fact that the weights include the recommendation parameter, it is not necessarily the case that a driver can find a route which gave him more comfort. He or she will maybe stay on a congested link.

D. Route Decision

If a driver does not feel comfortable anymore he triggers the model to calculate a new route. That means, if P_{od}^0 is the shortest path between origin o and destination d in the empty network and P_{od} the actual shortest path in the network that:

$$\begin{aligned} \text{if } c_v > 0 & \quad P_{od} = P_{od}^0 \\ \text{else} & \quad P_{od} = \min P_{od} \text{ in } G \end{aligned} \quad (5)$$

The actual shortest route is calculated with the Floyd-Warshall algorithm [3], which uses dynamic programming methodology to solve the All-Pairs-Shortest-Path problem. The algorithm runs in $O(|V|^3)$ time and negatively weighted edges may be present. Negatively weighted cycles cause problems with this algorithm, but this can be neglected because of the definition of the weight which are from \mathfrak{R}^+ . The main recursive definition of the algorithm is given by:

$$d_{ij}^{(k)} = \begin{cases} z_{ij} & \text{if } k = 0, \\ \min(d_{ij}^{(k-1)}, d_{ik}^{(k-1)} + d_{kj}^{(k-1)}) & \text{if } k > 0 \end{cases} \quad (6)$$

This algorithm above provides the shortest distance between all the vertices in an adjacency matrix. However, using the above procedure provides no information on the specific pathway that gives rise to these values. In order to construct the shortest pathway a predecessor matrix Π is required. A recursive formulation of the problem can be specified as:

$$\begin{aligned} \pi_{ij}^{(0)} &= \begin{cases} \text{Nil} & \text{if } i = j \text{ or } w_{ij} = \infty \\ i & \text{if } i \neq j \text{ or } w_{ij} < \infty \end{cases} \\ \pi_{ij}^{(k)} &= \begin{cases} \pi_{ij}^{(k-1)} & \text{if } d_{ij}^{(k-1)} \leq d_{ik}^{(k-1)} + d_{kj}^{(k-1)} \\ \pi_{kj}^{(k)} & \text{if } d_{ij}^{(k-1)} > d_{ik}^{(k-1)} + d_{kj}^{(k-1)} \end{cases} \end{aligned} \quad (7)$$

With this, all shortest paths in the network are recalculated and drivers can request their new route.

IV. RESULTS

For evaluation of the route choice model, two different scenarios have been created. First an artificial network with one origin and one destination with three different routes. The first route is a highway connecting the origin and destination, second a parallel urban route with a lower maximum speed and as third possibility a route through a city next to the motorway. The vehicle input is larger than the capacity of the highway and additionally a bottleneck on the highway is created by a maintenance site. In this scenario we assume that the drivers are on a long distance trip, and so will avoid inner city traffic.

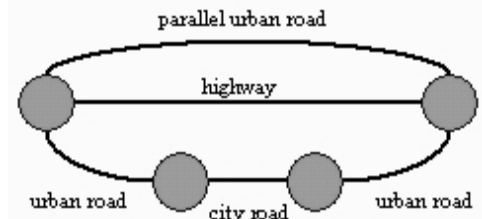


Fig. 1. Artificial network of the first test scenario. The origin and destination are the most left and right nodes. The length of the parallel urban route is 15% longer than the highway and limited to 100 km/h. The route through the city has the same length than the parallel route but has a different link type for the middle section.

The network was simulated for 3600 seconds and the routing decision of the vehicles was counted.

TABLE I
ROUTE DECISIONS FOR VEHICLES, ENTERING THE NETWORK IN THE FIRST HOUR OF SIMULATION UNDER DIFFERENT CONDITIONS

	Highway	Parallel	City
no advice	3588	14	0
en-route information	3264	338	0
full information	2850	614	138

If the route choice model is used without any additional en route information 3588 vehicles stay on the highway and only 14 vehicles switch to the parallel urban route. If a routing advice is given, the split changes to 3264 vehicles

on the highway and 338 vehicles on the parallel route. In both cases the route through the city center was not considered by any vehicle. Table 1 shows the results compared to the situation, when all drivers have full network information.

So it is shown that long trip vehicles avoid the city center and prefer to remain on the highway. If en-route information is given, drivers are switching to the parallel urban route expecting a lower travel-time. In a second test we took a closer look at the travel-time of the individual vehicles.

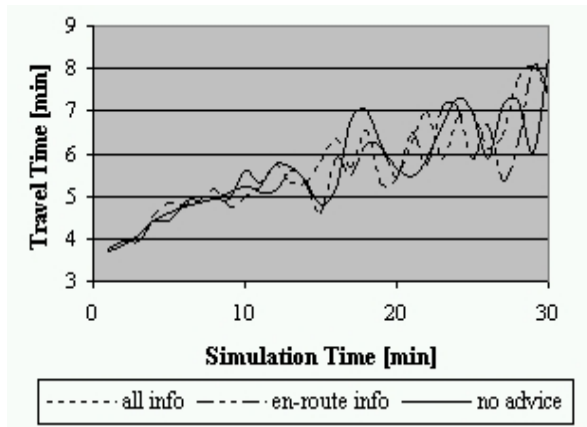


Fig. 2. Travel-time of individual vehicles from the origin to the destination. Before the congestion appears, the travel-time is nearly the same for all runs. After a cue is formed on the highway the travel-time starts oscillating. After the 30 minutes of simulation the travel-time remains between 7.6 minutes and 8.2 minutes.

In the figure above, it is good to see, that before the highway get congested, all runs deliver the same results. When the queue is forming the travel-time starts to oscillate. With no information the peaks start very high, because the driver has to see the congestion before he decides to change his route. The bandwidth get smaller if an en-route advice is given. If the driver has all information of the network (online route guidance system) the oscillation is very small. After 30 minutes of simulation the travel-time stays constant between 7.6 minutes and 8.2 minutes.

For the second scenario the network around the city of Delft was chosen. The network includes 118 node and 261 links including two highways and the major urban network of the city of Delft. The focus is on the vehicles coming from the South (Rotterdam), going to The Hague in the North. As input the online data from the 25th of February 2004 is used. On that day an accident on the A13 happened and the highway was highly congested. According to this, the amount of traffic on the connection in the south of Delft between the two highways was much higher. The online simulation run was started with the recorded data from one hour before the incident and after the detection of the

accident the first prediction, using the described route choice model was started.



Fig. 3. Delft network with two highways around the city and an urban connection in the south, as well as the major urban roads of Delft.

The measurements of this day are shown in the figure 4. It shows that around 10.50h an accident happened on the A13 direction Rotterdam to The Hague between the off-ramp Delft South and the off-ramp Delft.

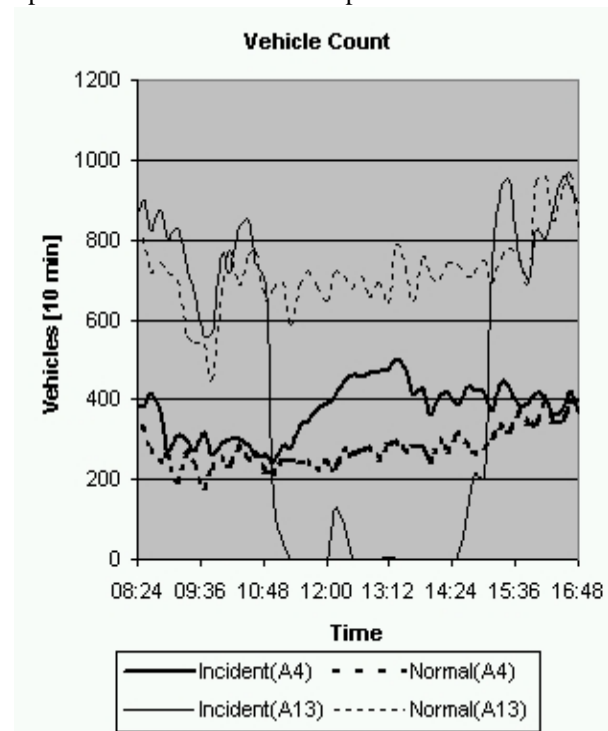


Fig. 4. Measurements on the A13 and A4 around Delft during the day of the incident. It shows very clear the shift of cars from the A13 to the A4.

After the A13 was completely blocked the traffic on the

A4 starts increasing to about the double amount of a usual day. At about 14.30h the closure of the A13 was over and it took about one hour until the normal traffic conditions on both road were restored. Another interesting part of the measurement is the peak around 12.00h. It is assumed that the police started to reroute cars to Rotterdam over the off-ramp Delft to clear up the situation. But for this paper we will not have a closer look at this point, because we are mostly interested in the shift of traffic from the A13 to the A4 and the share of vehicles going through the city and vehicles using the Kruithuisweg in the South of the city.

First we have simulated the time interval from 9.40h until 15.40h under normal traffic conditions, to calibrate the MiOS model. The bases for the normal traffic conditions are the online measurements from the day before the incident.

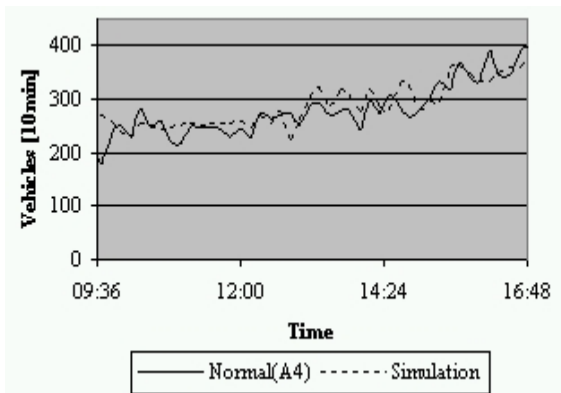


Fig. 5. Vehicle counts on the motorway A4 under normal traffic conditions, compared with the results from the simulation.

The results are shown in Fig. 5 and Fig. 6. Even if the model smoothes the actual counts, the outcome is satisfying. For both motorways the beginning evening peak is well represented. Due to the fact, that under normal conditions the A4 is not an alternative the results of both motorways are nearly independent and the route choice model does not effect the traffic counts for the traffic using the A13 from the South to the North.

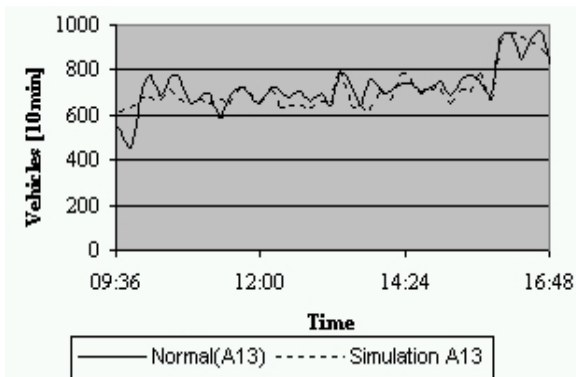


Fig. 6. Results of the simulation of the motorway A13 under normal traffic conditions, compared to the measurement.

For the simulation of the incident we have focused on the highway A4, because the A13 was blocked and the results would not be significant. Fig. 7 shows that the cars in the simulation model starts to switch routes faster, which can be explained by the differences between the traffic control programs in the model and the controller on the road. For the rest, the simulations satisfies our expectations.

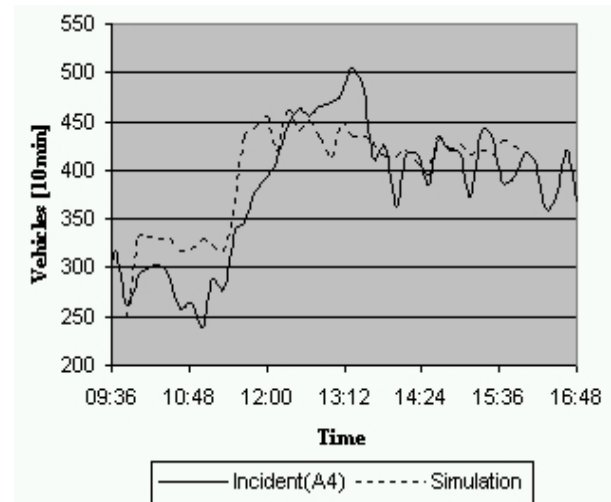


Fig. 7. This graph shows the measurement on the A4 and the simulation results of MiOS using the described route choice model. That cars switch the route earlier can be attuned by the parameters of the road type.

V. DISCUSSION

The results of the small artificial network show, that the route choice model, triggered by the view of the driver is able to simulate the routing decisions of individual drivers based on the information they get. If there is no information, the driver has to see the incident before he can react on it. So if the queue is in view, the driver maybe decides to switch to an alternatively route, but still refuses to make a detour through a center of a city. If he get en-route information the probability increases that drivers move from the highway to a given route, depending on the experienced reliability of this information. Additionally, it has been shown that in-car equipment leads to a split of the traffic to all available routes. Even when the shown results are at the boundaries of real conditions, the parameters of the route choice model allow a calibration to specific situation measured on the roads of the network.

That is proven by the use of the Delft network. Online measurements from the last year have been used to determine the willingness of drivers to switch routes. The simulator MiOS, used here, is able to learn and to attune these parameters during runtime. Predictions for these parameters are done, by comparing former simulation results with the according measurements. This particular

incident on the highway A13 was chosen as a challenge for the model, because these kinds of incidents do not happen weekly. But still the prediction was able to show the shift of traffic from the A13 to the A4 in the West of Delft. The measurements on the Kruithuisweg (urban connection of the highways in the south of Delft) were limited, because video detection is up to now only available on the opposite direction. So we used intersection detection for this part until we got the detections from the highway A4. So it is still to prove that the route choice for reaching the A4 is correct in the online simulation. Therefore more detection points in the city have to be considered.

VI. CONCLUSIONS

The results presented in the former paragraph show, that the described route choice model is able to deliver the expected results for artificial test networks. It was shown that the calibration of the parameters allow to change the results in the needed direction. Furthermore it was shown that the model is applicable for real-time online simulation models, like MiOS and is fast enough to handle even large networks.

For further research the model should be able to learn from differences in simulation and measurement and should be auto-calibrating to support the user. Additionally, the behavior model, based on link specific rules, will be replaced by using autonomous, reactive agents to simulate individual driving behavior more realistic. Therefore, data from a remote sensing project in the section will be used to train the underlying Bayesian network of each driving agent.

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