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RESEARCH ARTICLE

Iterative Calibration Method for Microscopic Road Traffic Simulators

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Abstract
Recently, computer simulation aided work has become a standard routine in all engineering fields. Accordingly, simulation plays a fundamental role even in road traffic engineering. A reliable simulator is able to provide effective analysis of a given traffic network if the applied simulation scenarios properly converge to the real-word situation. This requirement can be achieved based on the mixed use of prior real-world traffic measurements and proper simulation settings. The latter one, however, is not straightforward. Accordingly, the paper investigates a potential calibration technique to create realistic simulations. Basically, a tuning method with genetic algorithm is proposed to reproduce true-to-life traffic based on floating car speed data.

Keywords
microscopic traffic simulation, calibration, genetic algorithm

1 Introduction

In our days, the conscious transport planning and decision making is expected (Susnienė, 2012; Török et al., 2012; Meszaros and Torok 2014). Growing traffic demands together with the increasing motorization induce the continuous maintenance and development of road traffic control systems. In parallel, microscopic road traffic simulators forms an integral part of practical traffic engineering (Yurshevich and Yatskiv, 2014; Kollár, 2014). Appropriate traffic simulations constitute the preparatory working stage in such engineering tasks. Moreover, the applied ITS (intelligent transportation systems) solutions also require the appropriate traffic simulation based analysis. As a consequence, traffic simulators are more and more expected during both the development process and the validation phase as well.

On the other hand, the proper use of simulators is also important in order to avoid false results. Namely, beside the several advantages of computer based traffic modeling, simulators also contain the danger of providing erroneous results in case of inappropriate simulation settings in the scenarios. Accordingly, calibration of simulation parameters is expected. Numerous researches have been conducted in this field providing efficient methods to optimize the most important settings, such as travel times, driving behavior parameters, saturation flow rates, etc. These parameters are mostly microscopic variables which can be successfully tuned based on the existing research results, e.g. Columbia River Crossing (2006); Park and Schneeberger (2003); Cunha et al. (2009).

Contrary to the foregoing, in this paper, we focus on the tuning of a macroscopic variable exclusively: the traffic demand which is one of the most important network parameter in the microscopic simulation (represented by the intensity of vehicle sources in the simulator). Based on manual or detector measurement (if they are available), traffic demands can be appropriately estimated and therefore set in the simulation scenarios. However, in our days, the booming penetration of floating car data (FCD) creates a different approach. If real-world FCD is available from the road network to model, the average link speeds can be calculated, thus the traffic demand parameters can be efficiently calibrated.

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FCD is typically collected from fleet cars equipped with GPS receiver (provides accurate speed data and GPS position logs among others). Beside fleet cars, cellular phone based methods (server and client side as well) are also available to collect individual speed data of travelers (Tettamanti et al., 2012; Tettamanti and Varga, 2014). Another emerging technology is represented by the Bluetooth-based vehicle detection (Qing, 2011), which is already applied in few cities.

Apparently, the plethora of the novel measurement technologies offers the possibility to gather average traffic speeds for large networks. A well-known example is the traffic information functionality of Google Map or Bing Map. The sources of these maps are FCD information of fleet management companies and mobile data of private smartphone users. This service determines speed categories by using color codes displayed on the roads. Practically, the traffic speed on road links may be available. Therefore, the problem is simply given: how to create a reliable traffic model based on FCD speed information and without any traffic flow measurement? The solution is not straightforward as the traffic demand (traffic input flows) must be determined only from speed data. Note, that a given speed can be induced by different traffic inputs. Moreover, in case of a bigger traffic network, a combination of several demand flows has to be taken into account. Practically, this is a reverse engineering problem which solution in a closed form is not possible as it is highly underdetermined, i.e. several solutions are applicable as different combination of traffic demands might lead to the same average speed on a given link (regarding a bigger traffic network). As a result of these reasons, an online and iterative optimization is proposed to be applied for the problem.

Additionally, it is emphasized that the proposed method is based on raw GPS data of fleet cars (instead of color codes of traffic like in Google Map). Therefore, an appropriate preprocessing method is also suggested which must precede the calibration process.

The paper is organized as follows. After the Introduction, the proposed iterative calibration method is described. Then, the data processing method of the raw FCD is paraphrased. In the following part, a case study is introduced with simulation results. Finally, conclusions are drawn.

2 Iterative calibration based on genetic algorithm (GA)

As already introduced above, due to the available fleet car data, a new practical engineering problem to solve can be identified, which is very useful in the road traffic engineering. The basic task is to reveal traffic demand, i.e. vehicle input flows entering the network. To achieve this, FCD based average speeds of road links can be efficiently used, where a link can be determined as a road stretch between two signalized intersections. Moreover, measurement data of average turning rates of junctions need to be available. The microscopic parameters for the simulator setting such as driving behavior, lane change are assumed to be well calibrated based on any existing methods cited in the introduction part for example. Real-world signal settings (green time split, offset, cycle time) are known and used in the simulation.

Basically, the whole problem can be summarized as shown by Fig. 1 where the final goal is to calibrate the traffic demand in order to create realistic simulations.

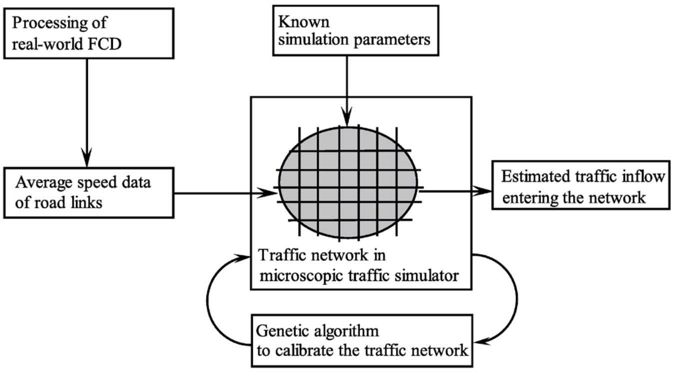

Fig. 1 The basic calibration problem

Typically, calibration problems can be fulfilled by some optimization process. The traditional method of optimization applies the derivative-based approach. However, if the objective function does not have a derivative, this approach cannot be used. In our case, the objective function contains a non-derivative term, i.e. the results of the microscopic simulation run. Practically, the optimization problem to solve is discontinuous, non differentiable, and highly nonlinear. Therefore, a potential solution is to formalize and solve the optimization problem as a genetic algorithm problem.

Moreover, the investigated optimization task is a non convex problem. The global optimum is unreachable in finite number of iterations in case of genetic algorithm. Therefore, the GA is applied to find only partial optimum. Basically, the GA was chosen instead of classical gradient based optimization methods, since the latter are more exposed to the starting points of the procedure (in case of GA a set of starting points are available contrary to the gradient based optimization).

The idea of using soft computing (Weise, 2008) for simulator calibration has already been recognized. However, the approach has only been used for the tuning of model parameters. In Cunha et al. (2009), a GA is used to optimize vehicle performance models in traffic simulators. In Aghabayk et al. (2013), the parameters of the car following and lane-changing dynamics of VISSIM simulator are tuned using the particle swarm optimization method. The traffic simulator PARAMICS is also calibrated by using a GA approach (Chu et al., 2003). The paper of Park et al. (2006) investigates a method for parameter optimization using a GA approach as well, tested in CORSIM and VISSIM simulators.

In our contribution, an iterative method is proposed (as depicted by Fig. 1) in order to fit the average link speeds to the traffic inflows. Basically, during the calibration process a discrete time window is iteratively simulated. The time window only moves on if the optimization criteria is fulfilled, i.e. the average speeds measured in the simulator do not differ from the real-world FCD speeds. This can be easily fulfilled by applying the *snapshot* option of the microsimulator, which means that the states of the simulation can be saved at any time. Therefore, the snapshot of the given time window is always stored and repeatedly reloaded at each iteration, until the time window may move on, i.e. until the optimal value is achieved within the given time window.

The applied fitness function of the optimization is given as follows:

$$J\left(Q(k)\right) = \min_{Q(k)} \sum_{i=1}^{n} \left\| \frac{\bar{V}_i^{FCD}(k) - \bar{V}_i^{Simulator}\left(Q(k)\right)}{\bar{V}_i^{FCD}(k)} \right\|_\infty .$$

$\bar{V}_i^{FCD}(k)$ is the average speed of link i originated from FCD information at time step k. $\bar{V}_i^{Simulator}\left(Q(k)\right)$ denotes the average speed of link i produced by the simulator in the previous simulation time window k. $Q(k)$ represents the applied vehicle input parameter.

Basically, the fitness function must be minimized within each time window. $J(Q(k))$ penalizes the relative deviation between simulated and real-world speed of each road link. The function is simply expressed as the infinity norm of the vector of traffic speeds. The GA based optimization runs within each time window until the termination criterion is achieved, i.e. $J(Q(k)) < \varepsilon$. For example, if termination parameter is set to $\varepsilon = 0.2$, the maximal admissible relative deviation of the average speed is 20%.

The complete calibration method is given by Fig. 2.

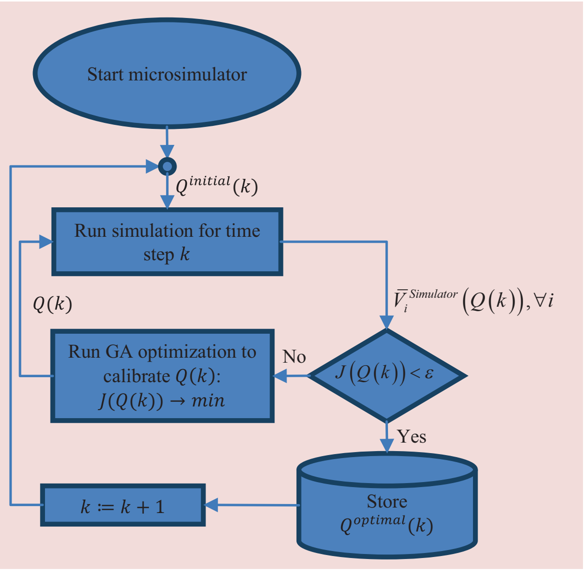

Fig. 2 General workflow of the iterative calibration of microscopic road traffic simulator

3 Real-world data processing to create average link speed functions

To test our calibration method, real-world traffic data has been applied. iData Ltd., a Hungarian company specialized in satellite-based fleet management, has provided GPS logs from fleet cars. For this purpose, a test network has been assigned in Budapest city center: a busy area with intensive road traffic (Fig. 3). The chosen road links are depicted in grey. The traffic is considered in both directions. Thus, FCD information of 8 test links in all has been considered.

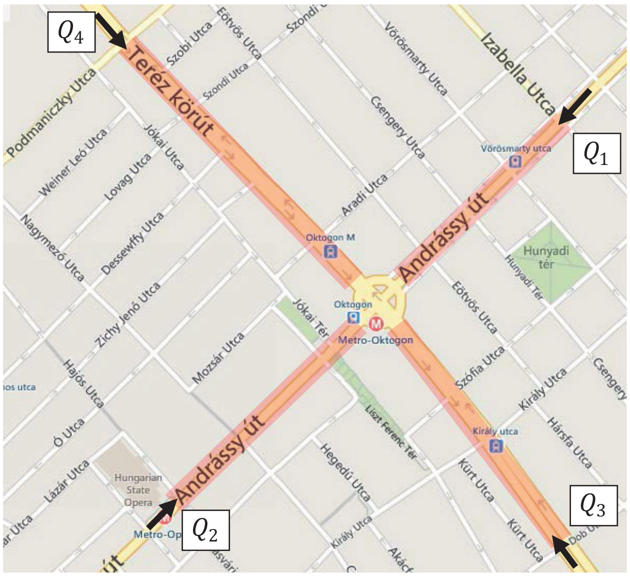

Fig. 3 The test network with 8 road links

The raw FCD, however, had to be preprocessed to create average link speed functions. Therefore, a trigonometric regression has been applied.

The aim of trigonometric regression, sometimes referred to as the Discrete Fourier Transform (DFT), is to identify significant periodicities (frequency components) within a finite sample of noisy temporal data. This is usually carried out by approximating our measurements with a linear combination of $2m$ $\left(m \in \mathbb{Z}^+\right)$ low frequency discrete and orthogonal sinusoids (m cosine and m sine curves). Note that it is not possible apply the conventional Fast Fourier Transform (FFT) procedure here, since a large portion of FCD can be missing. Hence, our method computes the coefficients a_0, a_l, b_l separately for each link i by minimizing the following l_1 regularized l_2 cost function (Tibshirani, 1996):

$$\mathrm{J}\left(a_0, a_l, b_l\right) = \min_{a_0, a_l, b_l} \frac{1}{2} \left\| y(k) - \left(\frac{a_0}{2} + \sum_{l=1}^{m} \left(a_l \cos \frac{2\pi lk}{p} + b_l \sin \frac{2\pi lk}{p} \right) \right) \right\|_2^2 + \lambda \left\| \left[a_0, a_l, b_l \right] \right\|_1$$

where $y(k)$ is the vector of observations, $k \subseteq \{1, 2, \ldots, p\}$ is the set of observed time indices and p is the periodicity. The first term is responsible for model fitness and the second term controls the model complexity. In our experiments, we set , $2 \leq m \leq 5$, $0 \leq \lambda \leq 0.5$ and $p = 288$, data was accumulated for several days with time windows of 5 minutes. $\bar{V}_i^{FCD}(k)$ was then fixed as the solution curve. In the numerical computations we used the CVX Matlab package (Grant et al., 2012; Grant and Boyd 2008) with SDPT3 (semidefinite-quadratic-linear programming) solver.

As an example for the applied trigonometric regression, Fig. 4 is presented. The figure depicts the regressed curve (average link speed) of one of the 8 test links concerning a 24 hours period.

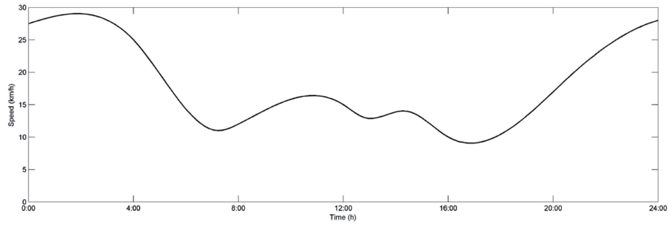

Fig. 4 Example for the trigonometric regression - the regressed speed function of a test link

4 Application of the calibration method

Users may choose among many different road traffic simulators. The greater part of them is commercial software. Additionally, open source simulators are also available, developed by universities or research institutes. Each of them has advantages or drawbacks depending on the individual demands of the user. In our paper, the applied environment is represented by VISSIM simulator (PTV, 2012a), widely used for diverse problems by traffic engineers in practice as well as by researchers. VISSIM offers a user friendly graphical interface which is not satisfying for several problems, e.g. to dynamically access VISSIM objects during simulation. For this end, an additional interface (PTV, 2012b) is offered based on the COM (Component Object Model) technology (Box, 1998). Accordingly, the integrated VISSIM-MATLAB environment is also applied in the calibration process (Tettamanti and Varga, 2012) as a state-of-the-art technology for advanced simulation.

To evaluate the proposed calibration algorithm, a case study was created. Based on the real-world average speed functions (introduced in the previous section), the test network was calibrated concerning a 2,5 hours long time interval. A peak period between 7:00 and 09:30 has been chosen for the better representation of traffic variation. The calibration workflow (given in Section 3) has been applied with 60 sec sample time and termination parameter $\varepsilon = 0.2$.

The applied optimization was used with the following parameter settings of MATLAB genetic algorithm:

- FitnessLimit: 0.2,
- Generations: 400,
- PopulationSize: 50,
- TolFun: 10^{-6}.

The variation of the fitness function $J(Q(k))$ can be observed in Fig. 5. This reflects the maximum relative error obtained during the calibration process, i.e. the worst difference between the link speed simulated based on the calibrated parameters and the real-world average speed functions. Practically, $J(Q(k))$ always remains under 22%, which can be considered a satisfying accuracy for calibration.

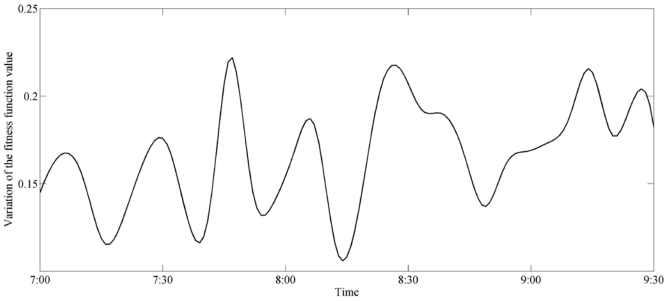

Fig. 5 The variation of the $J(Q(k))$ fitness function value

Finally, the calibrated traffic parameters (traffic input flows) are depicted in Fig. 6.

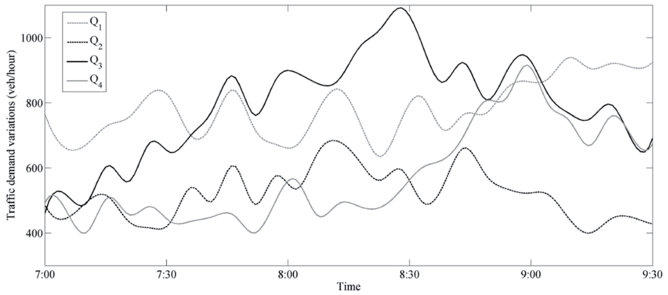

Fig. 6 The calibrated parameters, i.e. traffic demand variations

If these revealed traffic demands are applied in the simulator (as vehicle inputs to the network), fitness function $J(Q(k))$ is obtained shown by Fig. 5. This practically means that FCD data could be efficiently exploited in order to create realistic simulation.

The results of the simulations demonstrate that the GA based iterative optimization is well applicable for the tuning of road traffic simulators.

5 Conclusion

In our work, a genetic algorithm based calibration method is suggested for traffic simulators, reproducing realistic traffic conditions on a network represented by FCD data. The tuned variables of the simulation are the traffic flow inputs of the network. The obtained network link speed values should fit to the FCD speed data.

By using real-world floating car traffic data and a microscopic traffic simulator, the proposed calibration algorithm is efficiently applied and tested under different traffic conditions.

The proposed method was demonstrated by using the well-known VISSIM simulator. Nevertheless, it is emphasized that the technique can be applied for any type of microscopic traffic simulators.

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