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Evaluating the impacts of ITS applications using microscopic traffic simulators

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Abstract
Impacts of Intelligent Transport Systems (ITS) applications can be well estimated using microscopic traffic simulators. A necessary condition to achieve this is the correct implementation of the ITS functionalities into the simulators. In the studies described in this paper, the implementation has been realized in two ways: (a) by programming customized plugins for the Quadstone Paramics simulator, and (b) by linking the VISSIM simulator with the Swarco EC-1 traffic signal controller. The studied applications covered a bus priority strategy for signalized junctions as well as ramp metering algorithms. In both the studied cases, the simulators were able to reproduce functionalities of the implemented ITS applications well and provided a good environment for testing impacts of these applications. A special attention, however, needs to be paid to the interface between the simulators and ITS application modules.

Keywords – traffic simulation, public transport priorities, ramp metering, traffic control

1. Introduction
This paper focuses on integration of ITS applications related to traffic control into traffic simulators in order to evaluate impacts of these systems. The evaluation covers both traffic flow parameters as well as assessment of traffic safety indicators. The evaluated traffic control schemes include two cases:
1. the newly developed Finnish control strategy for bus priorities at signalized junctions SYVARI [2];
2. Ramp Metering algorithms.

Since such control schemes are not a standard part of the available traffic simulators, their implementation required customized programming using simulators software development kit [6] or using other third party software. The presented cases demonstrate flexibility of microscopic simulators to model various ITS applications as well as possibilities and experience with integrating traffic simulators with third party software and plugins.

This paper is organized as follows. Each case is described separately including background, model construction and results. At the end of the paper, a conclusion chapter then summarizes both the cases.
2. Case: SYVARI public transport priorities

SYVARI is a new traffic signal control strategy for implementing public transport priorities developed in Finland [2]. This strategy is useful for isolated junctions operating on coordinated fixed cycle control.

The main advantage of this strategy is its ability to maintain coordination between the junctions even after providing public transport priorities.

Before wider deployment, the SYVARI is currently being tested in order to evaluate its impacts to public transport vehicles as well as to other traffic. The test environment consists of the Swarco EC-1 controller simulator integrated with the VISSIM traffic simulator. This simulation environment has been previously used in the city of Stockholm for evaluating adaptive signal control and bus priorities [1].

In this environment, the VISSIM simulates vehicular traffic as well as several bus lines. The EC-1 controller simulator operates traffic lights in VISSIM based on the installed detector logic. For the purposes of this study, the VISSIM traffic model and the EC-1 traffic simulator run on different computers to improve stability of the system. Communication between these computers, consisting of vehicle detector data from VISSIM and traffic signal data from the EC-1 controller, is then realized via the TCP/IP protocol.

The test environment has been validated before collecting simulation data. The aim of this step was to ensure that the test environment provides reliable results. The validation consisted of two parts:

1. Ensuring synchronized operations of the VISSIM simulator with the EC-1 controller
2. Determination of the minimum length of simulation time to achieve robust results.

The synchronization requires that both the VISSIM simulator and the EC-1 controller run on identical speeds and the TCP/IP communication works without delays. The synchronization between VISSIM and the EC-1 was tested using a 24 hours long test simulation run. The synchronized operation was evaluated based on comparison of VISSIM simulation clock with the system clock of the EC-1 controller. In the performed test run, the observed difference between these clocks was negligible.

The communication delays between VISSIM and the EC-1 controller were evaluated indirectly from the coordination of traffic lights on three neighboring junctions in the VISSIM simulation model. At several stages of the simulation model, especially on the beginning and close to the end, operation of traffic signals in the simulator was compared to the original signal coordination diagram.

The coordination diagram defines timing plan for each of the junctions and time offsets between neighboring junctions.

Any delays or problems in communication between the VISSIM and the EC-1 controller would disturb the coordination of traffic signals in the model and as a result, the signals would no more operate according to the original plan after some time. During the testing, the signal coordination worked as defined during the whole simulation run and no deviations from the coordination diagram have been observed. These tests suggest that in the described test environment, the VISSIM and the EC-1 controller run synchronously and the communication between these two works without delays.

The second validation part focused on determining the minimum length of the simulation time producing reliable results.

For this purpose, results were collected from simulation runs of different length ranging from 1 to 3 hours.
Results of these runs were compared to a reference simulation run with an extreme simulation time of 24 hours. The comparison was based on mean values of the measured traffic indicators such as travel time or delays.

The length of the reference simulation time was considered as safe to produce stable results. The comparison revealed that there is extremely little if any statistical difference between mean values of the 3 hour simulation runs and the reference simulation run. These results lead to the conclusion that 3 hours represent a safe time to gain robust results from a simulation run minimizing the impact of stochastic factors within the run.

In order to use statistical means for the evaluation of simulated results, each of the simulation runs was repeated five times with different seed number in every scenario. This generated the total number of $5 \times 3$ hours = 15 hours of simulation time per one scenario. This corresponded to 15 observations per scenario if observations were measured hourly.

### 2.1. The simulation model and the evaluated scenarios

The performance of the SYVARI signal control strategy was evaluated using a model network consisting of three signalized four-leg junctions. Each junction was controlled by a separate EC-1 controller.

The junctions, referenced as A, B, and C, are arranged one after another and connected via a main road. The distance between the junctions A and B is 300 m, and the distance between the junctions B and C is 500 m. The length of the approaches to each junction is 500 m. There are four bus lines running across the network.

In the model network, the performance of the SYVARI was evaluated depending on several factors. The factors, listed below, are independent each from other and can be combined freely in the simulated scenarios:

- Bus priorities: in use / not in use
- Bus service intervals: 5 min, 15 min
- Traffic flows: normal Q1 (100 %), quiet Q2 (60 %), peek Q3 (125 %)
- Distance of bus detectors from stoplines:
  - V1 (base case): main road 200 m, side roads 150 m
  - V2: main roads 150 m, side roads 70 m
  - D3: main roads 70 m, side roads 50 m
  - D4: main roads 300 m, side roads 250 m

The scenarios where bus priorities are not in use serve as reference scenarios. The scenarios with active bus priorities can be compared to these reference scenarios in order to evaluate impacts of the priorities to different users of the road network. The two different bus service intervals represent cases of high and low demands for priorities. The three different traffic flow levels correspond to several periods of days where the effect of priorities should be evaluated. The position of bus detectors is a parameter influencing how early the signal controllers receive information about approaching busses. The earlier this information comes, the more time the controllers have to arrange priorities for the busses which are expected to gain from this situation. However, the more the busses gain, the more the rest of the traffic is expected to loose. In this context, the aim of the variable distance of bus detectors from junctions is to investigate this gain-loose tradeoff.
2.2. Evaluation and results

Core results of evaluation of the SYVARI traffic control strategy are presented at the Fig. 1 showing average delays experienced by busses in the whole studied network. In addition to the average delays, the figure also depicts standard deviation of the measured delays. In the figure, the horizontal axis represents the simulated scenarios and the vertical axis bus average delays per vehicle. The scenarios in the horizontal axes use the notation:

\[[\text{ON}|\text{OFF}] [5|15] [V1|V2|D3|D4] [Q1|Q2|Q3]\]

where:

- ON|OFF states for bus priority in use / not in use,
- 5|15 represents bus service interval 5 or 15 minutes, respectively,
- V1|V2|D3|D4 corresponds to the distances of bus detector from stop lines as described in the previous chapter
- Q1|Q2|Q3 represents normal, peek, and quiet traffic flows in the network, respectively.

![Fig. 1 - Delays experienced by busses in the SYVARI test network](image1)

![Fig. 2 - Delays experienced by vehicles without priorities in the SYVARI test network](image2)
The figure is divided into several regions depending on the bus service intervals (5|15) and the traffic flows (Q1, Q2, Q3).

As can be seen, the scenarios where bus priorities are not active cause significantly higher delays to busses compared to the scenarios with active priorities. From the scenarios with active priorities, the most favorable to busses are cases with the longest distance of bus detectors from the stoplines. As the distance of the bus detectors from the stoplines decreases, delays experienced by busses increase accordingly.

Similarly, the figure 2 shows the average delays and standard deviations for all vehicles except busses. The vehicles represented by this figure do not have priorities at the junctions. Compared to the previous figure valid for busses, this figure depicts opposite patterns.

The scenario without bus priorities, where busses experience the most delays, is the most favorable for the rest of the vehicles. Furthermore, differences among the other scenarios with active priorities in this figure form an opposite trend compared to the figure depicting bus delays. In another words, in the scenarios where busses gain time (experience smaller delays), the rest of the traffic looses. Accordingly, in the scenarios where busses loose time and their delays grow the rest of the traffic gains.

In addition to traffic parameter results, the simulation environment allows detailed collection of traffic signal data.

These data can be retrieved from two different sources:

i. directly from the EC-1 controller or
ii. from VISSIM log files. Traffic signal data are relevant for traffic safety assessments by identifying behaviors having negative impact to safety at the controlled junctions.

To summarize, impact of the SYVARI traffic control strategy has been demonstrated using the Vissim and EC-1 simulation environment. The results clearly show the benefits of this strategy for busses with priorities.

Additionally, the results also demonstrate effectiveness of the priorities based on local arrangements as the position of bus detectors. The presented results allow further analysis of the results. One way to analyze these results is to calculate cumulative delays for all vehicles in the network rather than delays per vehicle. This calculation takes the traffic flows into account hence allowing impact analysis for the whole network rather than for individual vehicles.

3. Case: Ramp Metering algorithms

Ramp Metering is a commonly used traffic control method, especially in the United States. The results obtained from various field studies demonstrate that the implementation of the ramp metering system has been remarkably similar all over the world: it provides a smoother flow of traffic and increases the average speed of the freeways.

In addition, implementing metering reduces fuel consumption, emissions and the number of freeway accidents. [5]. The main objective of the ramp metering system is to keep the traffic flow of the freeway undisturbed. This is achieved by keeping the traffic volume under its maximum capacity.

Although metering causes some delays to vehicles queuing on the ramp to the freeway, they also benefit from the system – ramp metering lengthens the headways on the ramp, giving more space for a single vehicle to accelerate, and thus increases traffic safety [5]. In Finland a simulation study [3] was conducted for examining the feasibility of ramp metering.
The simulation study was a part of the Ramp Metering project [5] [3], which consists of three phases: the preliminary study, the general plan and the implementation plan. The general plan introduces the technical and functional requirements for ramp metering in three junctions that were evaluated suitable for metering in preliminary study. The selected junctions Tuomarila, Karhusaari (Fig. 3) and Klaaukkala are located in Helsinki metropolitan area.

3.1. The model development

A simulation study was conducted with Quadstone Paramics for examining the feasibility of ramp metering. The study was conducted with two metering algorithms: ALINEA and RWSCOR. ALINEA controls the traffic flow of the on-ramp according to the formula (1):

\[ t = \frac{3600}{q_{zufluss} + k_r(b_{opt} - b)} \]

where:
- \( t \) = Cycle length
- \( q_{zufluss} \) = On ramp traffic flow
- \( b_{opt} \) = Optimal occupation rate of the downstream
- \( b \) = Current occupation rate of the Highway (measured by the downstream detectors)
- \( K_r \) = Constant

RWSCOR, on the other hand, calculates the cycle length according to the formula (2):

\[ t_k = \frac{3600}{(C - (Q_{k-1} + A(Q_k - Q_{k-1})))} \]

where:
- \( t_k \) = Cycle length
- \( C \) = Capacity of the highway (veh./h)
- \( Q_k \) = Current traffic flow of the highway (veh./h)
- \( Q_{k-1} \) = Traffic flow of the highway during the previous time frame (veh./h)
- \( A \) = Constant (0…1)
3.2. Results

The simulation study results show that ramp metering can improve traffic safety and the smoothness of the traffic flow in Tuomarila and Karhusaari junctions. The metering algorithms, however, still require some development work.

Ramp metering is not suitable for Klaukkala junction because of the remarkably high traffic flow on ramp. Ramp metering would have highest potential in decreasing main flow disturbances in Karhusaari. However, Karhusaari is one of the most saturated junctions in Helsinki metropolitan area and the bus lane arrangements are not favorable for ramp metering. For these reasons, Karhusaari would be a challenging test site. In Tuomarila junction, the biggest problem is the uphill ramp. In addition, Tuomarila junction requires more road construction work than other studied junctions. The figures Fig. 4 - Fig. 8 present the main simulation results of Tuomarila.

Fig. 4 - Average lane speeds at the Merge Zone without ramp metering - left lane with dashed line, right lane with solid line. (MYV1 = right lane at the upstream before the merge zone MYV2 = left lane at the upstream before the merge zone, MAV1 = right lane at the down stream after the merge zone, MAV2 = left lane at the down stream after the merge zone, MR = ramp lane at the beginning of the merge zone)

Fig. 5 - Average lane speeds at the Merge Zone with ramp metering ALINEA. Notation is the same as in the Figure 4
4. Conclusion

This paper has presented two examples of evaluating ITS applications by the means of microscopic traffic simulation.

The presented cases integrate commercially available simulators with additionally developed plugins or with other third-party software. While the simulators provide detailed analysis of the traffic flows in these cases, the plugins and third-party software implement the specific ITS functionalities.

An example of plugin development is demonstrated by the ramp metering algorithms simulation case. An example of integrating traffic simulator with third party software is demonstrated by the SYVARI public transport priorities simulation case. In both the examples, the integration worked well but it required special attention when setting up the simulation environment.

This was especially important in the SYVARI case where the traffic simulator and signal controller ran on different computers.

The presented integrated simulation environments also allow evaluation traffic safety relevant parameters.

This was especially demonstrated by the ramp metering case where traffic safety is assessed from the measured traffic flows parameters.

Nevertheless, also the SYVARI case simulation public transport priorities has a potential for traffic safety assessment.

In this case, the most safety relevant parameters relate to operations of traffic signals and their irregularities.

Relevance of irregular behavior of traffic signals to pedestrian safety has been recognized, among others, by Nash [4] based on experience with public transport priorities from the city of Zuerich.

Overall, integration of traffic simulators with plugins and other software represent new possibilities due to its ability to bring new functionalities into the simulators hence extending areas of their application.
Fig. 7 - Ramp metering, Tuomarila, key performance indicators during the peak hour, average speed and speed variations

Fig. 8 - Ramp metering Tuomarila, key performance indicators during the peak hour, average travel time and delays

References

