Hybrid Traffic Simulation with Adaptive Signal Control

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Abstract

In this paper we implement and apply a hybrid mesoscopic-microscopic model that applies microscopic simulation to areas of specific interest, while simulating a large surrounding network in lesser detail with a mesoscopic model. The hybrid model integrates VISSIM, a microscopic traffic simulation model, and MEZZO, a recently developed mesoscopic model. The hybrid model is applied on a network where MEZZO simulates the entire Stockholm area (6000 links) and VISSIM simulates the area of specific interest containing three intersections with adaptive signal control with bus-priority functions. The adaptive signal control and bus-priority functions are simulated by a separate signal controller simulator (EC1-simulator) which interacts with the hybrid MEZZO-VISSIM model, thereby providing the actual signal changes that would take place in the field. Two alternative control schemes are evaluated using the hybrid set-up: the original fixed-time control and the new adaptive control. The results show clear improvement in terms of travel times, delays and stops with the new adaptive control scheme. They also show that while these improvements for the local (micro) area attract additional traffic from the surrounding (meso) area, the net effects both locally and network wide remain positive, in terms of travel times, average number of stops and delay. Moreover, this paper demonstrates the advantages of hybrid simulation in evaluation of complicated adaptive traffic control where both local detailed effects as well as network effects need to be studied.

Keywords: Traffic simulation, Adaptive Signal Control, Mesoscopic, Microscopic, Hybrid

1. INTRODUCTION

Traffic simulation has become popular for modeling the operations of dynamic traffic systems. Traffic simulation models can be classified as macroscopic, mesoscopic or microscopic. Macroscopic (macro) models (e.g. Strada *(1)*, Metacor *(2)*) tend to model traffic as a continuous flow, often using formulations based on hydrodynamic flow theories. Mesoscopic (meso) models (e.g. DynaMIT *(3)*, DYNASMART *(4)*) model individual vehicles, but at an aggregate level, usually by speed-density relationships and queuing theory approaches. Microscopic (micro) models (e.g. MITSIMLab *(5)*, VISSIM *(6)*) capture the behavior of vehicles and drivers in great detail, including interactions among vehicles, lane changing, response to incidents, and behavior at merging points. Because of this level of detail in the representation of traffic dynamics, microscopic models are appropriate for evaluation of ITS systems at the operational level, since the representation of many dynamic traffic management systems requires such fine-grained modeling of the traffic process.

However, due to the detailed nature of microscopic models, the preparation of input data (e.g. network coding and representation) can be very time consuming and tedious. In addition, micro models are highly sensitive to errors or variation in input demand data, especially under congested conditions and their calibration is not trivial. Therefore, microscopic models are usually applied to smaller networks. Macro and meso models usually have fewer parameters to calibrate and are less sensitive to errors in network coding or demand variations. On the other hand, due to their more aggregate nature, such models are limited in their ability to capture the detailed behavior needed to study traffic networks with dynamic traffic management capabilities.

Recently, hybrid macro – micro models *(7-12)* and meso – micro models *(13-15)* have appeared, attempting to combine the strengths of macro or meso simulation (large networks, less sensitive to network coding errors, easier to calibrate) with those of micro simulation (greater detail, ability to model and evaluate ITS and adaptive traffic control). Such hybrid models enable the simulation of large scale networks, incorporating the effects of local micro phenomena. This increases accuracy and validity while reducing the required data collection and calibration effort of the overall model.

Until now, these hybrid models have been tested mostly using very simple networks, often consisting of a number of consecutive links, where one or more links in the middle of the sequence are simulated in micro and the others in meso or macro *(7-12)*. In most cases the micro models are kept very simple, not even including lane-changing. However, in *(13,14)* the hybrid model (MEZZO – MITSIMLab) was applied to a small Stockholm network where the south part consisting of intersections and a roundabout was simulated in micro (MITSIMLab *(5)*) and the remainder in meso (MEZZO *(14)*).

In this paper we implement the hybrid framework presented in *(13,14)* using a different micro model, VISSIM *(6,16)*. The replacement of the open source MITSIMLab for a commercial micro model has had a number of consequences for the implementation of the framework, which will be discussed here. In addition, a simulator program for the adaptive signal control (EC1-simulator) is interfaced with the hybrid model, thereby providing the actual signal changes that take place in the field. The new implementation of the hybrid model (named InterMezzo) is applied on a network where MEZZO simulates the entire Stockholm area (6000 links) and VISSIM simulates the area of specific interest containing three intersections with adaptive signal control with bus-priority functions. The City of Stockholm has changed the signal control scheme to improve the traffic performance of the intersections. This new scheme is evaluated against the old signal control using the advantages of the hybrid model, combined with the signal control logic as it is implemented in the field.

The remainder of the paper is organized as follows. Section 2 discusses the hybrid framework. Section 3 describes the implementation of the hybrid framework using VISSIM and the integration and synchronization with the EC1 signal controller simulator. Section 4 presents the case study and its results and section 5 provides some discussion. Finally, section 6 draws conclusions summarizing the paper.

2. MESO-MICRO INTEGRATION FRAMEWORK

In *(13,14)* the conditions for a consistent hybrid meso – micro simulation model were presented, and a hybrid integration framework was proposed that satisfies these conditions. In this section the requirements and framework are introduced briefly. The requirements for a successful hybrid model are:

- Consistency in route choice and network representation
- Consistency of traffic dynamics at meso-micro boundaries
- Consistency in traffic performance for meso and micro submodels
- Transparent communication and data exchanges

2.1 Consistency in route choice and network representation

In *(13,14)* a general architecture is proposed, consisting of a separate module that contains elements common for the meso and micro models: a *database* with the network graph, the travel time tables, the set of paths and the origin-destination (OD) flows, as well as a *travel behavior* component with route choice models and path generation algorithms. This general architecture is applicable when new models are developed, with integration in mind.

In addition *(13,14)* present a simplified framework for the integration of existing models that minimizes inter-model communication overhead and uses functionalities in both models (such as route choice) in a consistent manner.

In the simplified framework the meso model includes the OD matrix for the entire network. This assumption is by no means restrictive, since an origin or destination node in the micro area can always be designated as a boundary node in meso connected directly to the micro subnetwork.

In addition the meso network includes *virtual links* for each path connecting boundary nodes in the micro network. This representation guarantees that each relevant path through the micro model is represented correctly in the meso route choice. The meso model collects travel times for the virtual links from the corresponding paths in micro, and uses them in the route choice like any other link in the network.

Under this simplified architecture the meso model is solely responsible for all pre-trip routing decisions. En-route decisions are the responsibility of the respective subnetwork and paths *inside* the meso model. In this paper the simplified architecture is implemented using the meso model for the overall routing.

2.2 Consistency of traffic dynamics at meso-micro boundaries

In *(13,14)* the modeling of traffic dynamics at meso-micro boundaries is discussed in detail. One of the main sources of potential inconsistencies at the interface between the meso and micro models are the correct determination of crossing vehicle attributes in both directions (micro → meso) and (meso → micro). Attributes such as speeds, accelerations, headways, etc should be consistent with the prevailing conditions in the new segment the vehicle is moving to, otherwise unnecessary shockwaves may propagate upstream.

On the boundary from the meso to the micro **(meso → micro)** submodel information is exchanged in both directions. From meso to micro information about vehicles (with a certain speed and at certain time intervals) needs to be communicated. From micro to meso information about blocking of boundaries and downstream density needs to be communicated. If the entry to the micro link (downstream of the boundary point) is blocked, the meso needs to stop vehicles from exiting. The micro model informs meso when the blockage is removed so that vehicles can start flowing again (over that specific boundary). The micro also sends the density in the vicinity of the boundary to meso, where it is used to calculate the speed of the shockwave that propagates upstream.

A more complicated issue is the generation of information that is needed in the micro representation of traffic, but missing in the meso. The micro characteristics that need to be generated at the entry to the micro model are divided into vehicle/driver *attributes* and *model variables*. Attributes such as desired speed are generated independently in micro based on the distribution of these characteristics in the general driver population assumed by the micro model. Model variables, such as the vehicle's speed, acceleration and time headway to the vehicle in front, need to be *in accordance with the traffic situation upstream and downstream of the boundary*.

In the interface from the micro to the meso model **(micro → meso)** similar conditions need to be met as mentioned in the meso to micro case. Firstly, the meso needs to inform the micro each time the downstream meso link becomes blocked or unblocked, so that the micro model can stop/start sending vehicles at the right moments. In addition to the blocking, the vehicles in micro that move towards the exit to meso need to react to the downstream traffic conditions, as they would if the downstream link were micro as well. In that case the vehicles would react to vehicles in front using their car-following logic, and those vehicles would react to vehicles in front of them, etc. In the meso model, however, the position and detailed behavior of vehicles is not usually modeled. But it is known when the latest arrival of a vehicle was and the (average) speed it was assigned. Using this information a *virtual vehicle* is projected in the "imaginary" continuation of the micro link. Vehicles in micro that are near the exit *react to the virtual vehicle* as if it were a normal vehicle in front of them. This concept can be extended to provide one virtual vehicle for each lane on the micro link.

2.3 Consistency in traffic performance for meso and micro and transparent communication and data exchanges

In addition to the conditions in 2.1 and 2.2, the meso and micro submodels need to be calibrated carefully to ensure that facilities that can be modeled by both submodels have similar capacity in meso and micro. Furthermore, the models need to communicate information (vehicles, traffic conditions, etc.) efficiently without too much overhead. For more information see *(13,14)*.

3. IMPLEMENTATION OF HYBRID FRAMEWORK

The framework described in *(13,14)* and briefly introduced in section 2 is implemented using MEZZO *(14),* an event based mesoscopic model, especially developed for hybrid modeling, and VISSIM *(16),* a commercially available state-of-the-art microscopic model.

In *(13,14)* the micro model for the hybrid prototype was MITSIMLab, for which the entire source code was available. This enabled a full integration of the common components of the micro and meso model (such as the route choice) and easy adaptation of the models for vehicle dynamics to allow for improved vehicle loading at the micro → meso boundaries and virtual vehicles at the meso → micro boundaries. While this implementation was very versatile, MITSIMLab is for the most part an academic model with few commercial users. For hybrid modeling to become available to a wider public of micro model users, the hybrid framework was re-developed and re-implemented using VISSIM.

While it is not possible to change the source code of VISSIM to obtain the desired hybrid functionality, VISSIM does offer a COM API *(17)*, which is a programming interface where the user gains access to all internal objects using any type of programming language that can manipulate COM objects (such as C++, Visual Basic or Visual Basic for applications (VBA)). This means that most objects available within VISSIM (links, vehicles, paths, etc.) can be accessed, and their attributes manipulated, but no new object types can be added, nor can any objects (such as vehicles, and their car following behavior) be modified (added attributes, different functionality). This implies that while most of the proposed architecture could be implemented directly, some of the functionality (such as virtual vehicles and paths) had to be implemented in a different way.

3.1 Network and route representation

The routes in VISSIM consist of a series of user defined 'abstract' nodes on top of the link-based network, usually one for each intersection. The standard network representation of VISSIM is based on links and link-connectors only. Routes are part of the dynamic traffic assignment add-on, which enables users to define origin-destination demand via parking lots in the network and routes between these parking lots using superimposed nodes. The implementation of the hybrid framework uses the meso *virtual links* as described in section 2. These virtual links represent the paths inside the VISSIM network, connecting inbound (meso → micro) and outbound (micro → meso) boundaries. The virtual links are then part of the meso network representation and are treated by the route choice model in the same way as the regular meso links. In particular, each virtual link description consists of:

1. The outbound and inbound meso boundary nodes.
2. The start and end parking lots in VISSIM.
3. A sequence of nodes representing the path inside VISSIM from the start to the end parking lot.

In the meso model (MEZZO), a list is maintained of all vehicle objects currently in VISSIM. When they re-enter the meso network their travel times are logged for the virtual link they have been on. This allows the meso model to account for the pre-trip routing throughout the model (see *(14)* for more details). In *(13, 14)* an additional construct *micro virtual links* was presented to handle en-route diversions inside the micro model, since such diversion may require a different exit point into the meso network. While it is possible to implement this construct in the future, it was deemed outside the scope of this implementation, especially since the size of micro networks used in a hybrid setting (a small number of intersections) usually do not require this functionality.

3.2 Traffic dynamics at meso-micro boundaries

The vehicles are arriving in micro from the meso model with time headways determined by the node servers in MEZZO, where each outgoing lane has its own (stochastic) server process (see *(14)* for more details). Whereas in MITSIMLab the vehicle loading was modified to generate initial speeds that were in accordance to the time headway from the leading vehicle in the selected lane, in VISSIM these adaptations are much more difficult to make. This is due to the fact that in VISSIM only existing objects, and their attributes can be accessed and modified through the COM interface, not the internal functionalities such as the vehicle loading mechanism. In addition, as shown in *(18)* the standard loading of vehicles in VISSIM generates much less artificial decelerations and capacity problems than the original MITSIMLab method. When a vehicle crosses the boundary to VISSIM it is created in a parking lot and assigned its (VISSIM) path, whereupon the standard loading mechanism assigns it a lane and a speed (see *(18)* for details). The parking lots are modeled as ‘abstract lots’ meaning that the vehicles do not start from standstill, but leave immediately at an appropriate initial speed *(16, 17)*.

Queue spillback across the meso-micro boundaries is taken care of by checking at the end of each VISSIM time step if there are any vehicles in entry parking lots that have not been able to leave (due to congestion ahead). If this is the case, the virtual links to which the ‘queued’ vehicles belong are ‘suspended’ (blocked), meaning that no more vehicles for these virtual links are sent to the micro area, until the parking lots become ‘unblocked’ and the queued vehicles have left. When a virtual link is ‘suspended’ the upstream MEZZO link stops sending vehicles to it, and a queue starts to build up on that link. After the blockage disappears, the start-up shockwave that traveled in the microscopic model (VISSIM) towards the meso-micro boundary, continues inside the meso, ensuring a correct arrival process at the meso-micro boundary (See thesis *(14)* for details).

In section 2, the concept of virtual vehicles was described to ensure that vehicles exiting from the micro into the meso model have the appropriate speed (according to the speed in the downstream meso link). As with the vehicle loading, this concept is difficult to implement in VISSIM since it requires modification of the car following model, allowing a vehicle to follow a ‘virtual vehicle’ projected past the end of the link. Instead, the same idea was implemented by modifying the speeds of the exiting vehicles directly according to the following rules.

For each vehicle on an ‘exiting’ link in VISSIM:

1. $V = V_0$, if $X > X_{Lookahead}$, or if $V_0 \leq V_{MEZZO}$.
2. $V = V_{MEZZO}$ if $X < X_{Critical}$, and $V_0 > V_{MEZZO}$
3. $V = \alpha V_0 + (1-\alpha)V_{MEZZO}$, where $\alpha = X / X_{Lookahead}$, if $X_{Critical} < X < X_{Lookahead}$, and $V_0 > V_{MEZZO}$

Where,
V = new speed of the vehicle
V_0 = initial speed of the vehicle
V_{MEZZO} = speed on the downstream link in MEZZO (which is a function of the density on that link)
X = distance of vehicle to the exit point
$X_{Lookahead}$ = distance to exit point from whereon the vehicle’s speed is influenced by the speed in the meso segment downstream
$X_{Critical}$ = distance to exit point from whereon the vehicle’s speed is set to the speed of in the meso segment downstream
α = smoothing parameter

$X_{Lookahead}$ and $X_{Critical}$ were set to 150m and 10 m respectively, but should be calibrated.

Equation 1 implies that if a vehicle is further than the look-ahead distance away from the exit point, its speed remains unchanged. Equation 2 sets the speed of the vehicle to that of the downstream MEZZO segment if it is within critical distance of the exit point. Equation 3 implies that if the vehicle is at a distance between the lookahead and critical distances from the exit point, its speed is interpolated between its current speed and the speed in the downstream MEZZO segment, depending on its distance from the exit point. The closer it is to the exit point, the closer its speed will be to the speed in the MEZZO segment. All of the above under the condition that the MEZZO segment speed is lower than the vehicle’s current speed.

If a meso link downstream of a micro-meso boundary becomes blocked (due to congestion), the above mechanism also ensures that the VISSIM vehicle at the end of the micro link is stopped. Conversely, when the blockage disappears the density in MEZZO decreases, allowing the vehicle to exit as soon as a space at the beginning of the MEZZO link becomes available. Since MEZZO represents the start-up shockwave explicitly, a vehicle exiting *downstream* from a fully congested (MEZZO) link does **not** immediately result in space becoming available *upstream* (at the end of the queue). Instead the shockwave speed is calculated and the space becomes available with a delay (see *(14)* for details).

Another important note is that the speeds of the vehicles queued in VISSIM (to enter the meso link) are only modified in case they are higher than the speed in MEZZO. So in the case of a start-up shockwave following the dissipation of a queue that has blocked back into the micro area, the speeds of the vehicles in VISSIM remain untouched, allowing the (superior) microscopic mechanisms in VISSIM to take care of the propagation of the start-up shockwave when it passes the micro-meso boundary.

3.3 Inter-model communication and synchronization

Whereas in *(13,14)* the synchronization of the two submodels was managed by MITSIMLab, the different implementation of VISSIM and its COM interface requires MEZZO to control the synchronization. Each VISSIM timestep (typically 0.1 sec) is an explicit event in the MEZZO eventlist, and for each ‘VISSIM event’ MEZZO executes exactly one VISSIM time step itself, whilst calling VISSIM to do the same. At the end of this event MEZZO checks if there are any vehicles that exited VISSIM to enter MEZZO. In addition it checks the VISSIM entry parking lots for space for new vehicles, sends any new vehicles into VISSIM where possible, and modifies the speeds of vehicles in VISSIM approaching exits to MEZZO. While it is possible to reduce the frequency of communication of traffic conditions and vehicles to decrease the communication overhead, this may introduce some errors in vehicle loading due to vehicles being entered slightly delayed. The current set-up was deemed sufficiently fast.

3.4 EC1 Signal control simulator

One of the most common signal controllers used in Sweden is the Peek Eurocontroller EC1 *(19)*. Part of the programming toolkit for the EC1 is a signal controller simulator with which signal plans for the EC1 can be tested and evaluated on a personal computer, before implementation in the field. This simulator uses the exact same signal control logic as the real signal controller in the field. This simulator has been coupled to VISSIM (figure 1) to simulate the control strategy exactly as it is implemented for the three signalized intersections. The EC1-simulator / VISSIM interface translates detector readings from VISSIM to the controller inputs and signal status in the controller to red, amber and green orders in VISSIM. Multiple EC1-simulators are controlled and coordinated via EC1-SimulatorControl, which is also used to configure the VISSIM – EC1-simulator connections.

The detector status needs to be updated 10 times / sec in order to make the EC1-simulator work as a real signal controller in the street, and therefore VISSIM needs to have 0.1s time step when the EC1-simulator is connected. Another challenge with the EC1-simulators is the absence of time synchronization with VISSIM, the EC1-simulator is set to a fixed speed which it will keep regardless of VISSIM's simulation speed at the moment. This means that VISSIM (and likewise the hybrid InterMezzo) needs to keep a predefined simulation speed when connected to the EC1-simulator. A function that keeps a fixed simulation speed, eg. real time or 2 x realtime, is therefore implemented in InterMezzo.

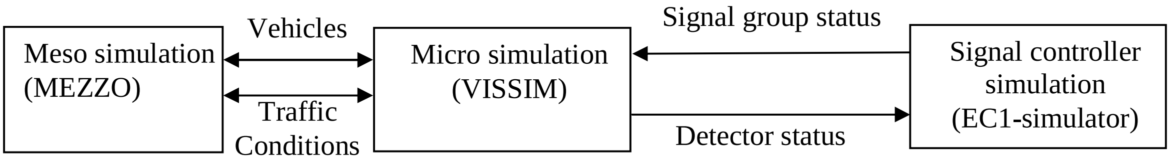


FIGURE 1. Hybrid Meso-Micro model (InterMezzo), interfaced with EC-1 simulator

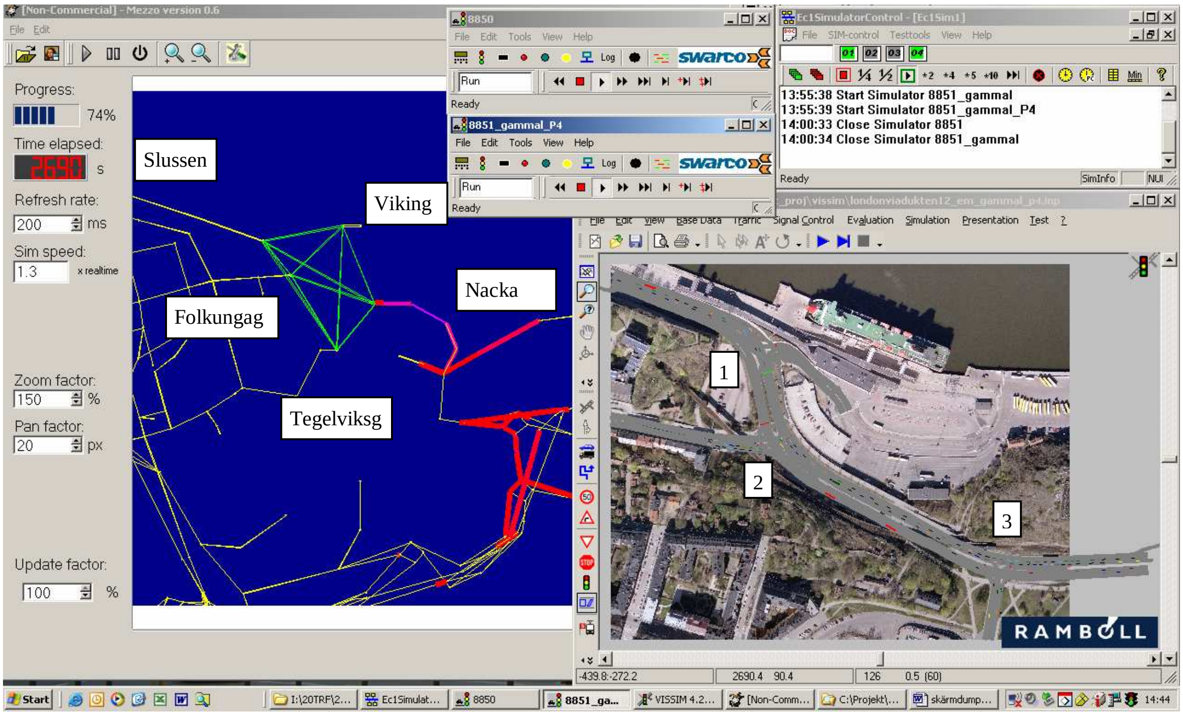
4. CASE STUDY

The implemented hybrid model, InterMezzo, is applied on a network where MEZZO simulates the entire Stockholm (6000 links) and VISSIM simulates a small portion on the south-east border of central Stockholm, containing three signalized intersections, with adaptive signal control, bus lanes and bus priority functions in the signal control.

Recently improved adaptive signal control was implemented for these intersections, and this new signal control scheme is compared against the original scheme, using the hybrid model. When the capacity of a highly congested facility, such as this one, is improved drastically, it can be expected to draw additional traffic from alternative routes, which in its turn can be expected to partly off-set the achieved improvement. To study such redistribution effects a large surrounding area needs to be simulated, larger than is practical to study with a microscopic model, due to the extensive network coding and calibration efforts needed. The InterMezzo hybrid model, however, allows such a study of a large surrounding network together with the microscopic precision of the area of specific interest.

4.2 Study area

The area of specific interest (Londonviadukten) simulated in VISSIM is part of a main arterial from the south-east of Stockholm into central Stockholm. (See figure 2). The capacity of this part of the arterial is limited mainly by a number of signal controlled intersections periodically resulting in long queues, especially for traffic Nacka in the morning peak hours. Furthermore, Londonviadukten is an important arterial for the bus lines connecting the south-east to central Stockholm, especially since this part is not connected to the Stockholm subway network. Buses make up a large portion of the traffic, around 8% in the morning peak hour. While the busses travel mostly on separate bus lanes in the study area, they have a large impact on the other traffic due to bus-priority rules in the signal control and the fact that the bus lanes end before each intersection (to make place for right-turn pockets). The actual bus lines, stops and timetables are coded within VISSIM. Since MEZZO does not yet have these public transport facilities (bus lines, bus routes etc.) the busses are simulated within VISSIM only. As a result of this the traffic flows on some roads in the MEZZO part of the model are somewhat lower than they should be.



Progress: 74%
Time elapsed: 2690 s
Refresh rate: 200 ms
Sim speed: 1.3 x realtime
Zoom factor: 150 %
Pan factor: 20 px
Update factor: 100 %

```
13:55:38 Start Simulator 8851_gammal
13:55:39 Start Simulator 8851_gammal_P4
14:00:33 Close Simulator 8851
14:00:34 Close Simulator 8851_gammal
```

FIGURE 2. Londonviadukten in MEZZO(left) and VISSIM (bottom right), with EC1 simulator (top right). The green lines in MEZZO represent the area simulated by VISSIM.

The old signal control scheme for intersections 1 and 2 (in figure 2, VISSIM) was fixed-time during the morning peak hour. The new control scheme for these intersections uses vehicle actuated Swedish signal-group control (LHOVRA). The two intersections are coordinated through fictive signal-groups that can obtain green waves by delaying, shortening or extending respective phases in the other intersection. For more information please refer to (20) (21) (22). The original fixed-time control would cause long queues towards Nacka during the morning peak hour.

For intersection 3, the signal control scheme is the same in both scenarios, local vehicle actuated signal-group controlled (LHOVRA) with bus priority (PRIBUSS) (22) for buses towards Nacka. The bus priority modifies the standard functioning of the signal control to a large degree and includes green extensions as well as shortenings, phase recalls and extra bus phases. The bus priority can cause long delays for traffic from Nacka. While the signal control in this intersection is not co-ordinated with the other intersections, their operations influence each other due to their proximity.

The large surrounding network simulated by MEZZO, spanning the entire Stockholm, has been imported from CONTRAM-8 *(23)* format. In addition the demand is converted from CONTRAM time-dependent OD (Origin / Destination) matrices that were calibrated previously to fit traffic measurements (flow counts) for a number of main roads, freeways and arterials.

The area that is now simulated by VISSIM has been cut out of the meso network, and replaced by the virtual links discussed earlier (the green lines in figure 2, MEZZO). The demand was calibrated additionally by selecting a number of OD pairs that had routes through the VISSIM network, to match flow counts from the City of Stockholm for most of the ingoing and outgoing links. The simulation period for both scenarios was 1 hour, 7:00 – 8:00 AM, of which the first 10 minutes were used as warm-up period (to allow traffic to enter the network and reach the VISSIM area).

4.3 Discussion

To reduce the number of replications / iterations needed, MEZZO was run in deterministic mode, with 5 iterations for each scenario to reproduce possible redistribution effects. VISSIM was run with the same random seed to avoid deviations due to stochasticity. The authors recognize that preferably MEZZO should be run in stochastic mode and both models should be replicated with different random seeds to obtain reliable results that reflect the complete range of stochastic variation of the traffic processes modelled. See *(24)* for a detailed discussion on the method and number of replications needed to create reliable confidence intervals for the means of a certain set of output measures of performance. Nevertheless, the largest source of stochastic variation in VISSIM is probably the arrival process of vehicles, which in our case has been replaced by the arrival process from MEZZO.

In addition, the Stockholm network used in MEZZO had been only partly calibrated (previously, using CONTRAM and here locally to match measured flows through the area of interest). In a parallel project the network is being extensively calibrated using a large set of measurement data including speeds, flows and travel times.

Moreover, MEZZO is being extended to incorporate public transport such as buses, bus lanes and time tables. This should improve the quality of the hybrid simulation, since in this application the simulation of bus operations was restricted to the VISSIM microscopic area.

4.4 Results

Table 1 shows that traffic flows from Nacka towards Stockholm city in the morning peak hour increase with 23% or 470 vehicles with the improved signal control. The improved traffic conditions in the studied area have probably attracted traffic from alternative routes. The other differences in traffic flows are small in absolute numbers and can, at least partly, be a result of variation in the signal control start up states (the start up state of the signal controller simulator is not deterministic). In the direction from Slussen there is only a small increase in traffic flow, but on the other hand, the improvement in traffic conditions in this direction during the morning peek hour is not that big either. The traffic flows from Folkungagatan have deceased with 3% or 18 vehicles and from Tegelviksgatan with 11% or 13 vehicles. One possible reason for the decreased flows from the minor approaches may be that traffic is attracted to alternative routes due to changes in traffic flows in other parts of the MEZZO network outside the studied area. In total, the traffic going through the VISSIM area increased with 453 vehicles or 12%.

	Signal control		**Difference**	
	Old (veh/h)	*New (veh/h)*	*abs.(veh/h)*	*rel. (%)*
Folkungag	607	589	-18	-3%
Slussen	919	934	14	2%
Nacka	2032	2502	470	23%
Tegelviksg	124	110	-13	-11%

TABLE 1. Flows into the micro area (VISSIM) with old and new traffic control strategies

	Signal control		Difference	
	Old	*New*	*abs.*	*rel.*
Average speed [km/h]	22.0	28.3	6.3	29%
Average delay time per vehicle [s]	369.0	268.0	-101.0	-27%
Average stopped delay per vehicle [s]	161.4	111,.3	-50.1	-31%
Average number of stops per vehicle	10.5	7.7	-2.8	-27%

TABLE 2. Results from micro area (VISSIM) with old and new traffic control strategies

The results in VISSIM (Table 2) show that the average speed for vehicles in the area of interest has increased with 29% from 22 to 28 km/h. At the same time the average delay per vehicle has decreased with 27% from 369 sec to 268 sec. The average stopped delay per vehicle has also decreased, with 31% from 161 to 111 sec and the average number of stops has decreased with 27% from 10.5 to 7.7. This means that with the new signal control the local conditions have improved inside the area of interest, *in spite of the increased flow from the main approach into the area*, caused by redistribution of flows from MEZZO in reaction to the improved local conditions.

	Signal Control		Difference	
	Old (sec)	*New (sec)*	*Abs (sec)*	*Rel. (%)*
Nacka - Slussen (1)	705	337	-367	-52%
Nacka - Slussen (2)	778	381	-397	-51%
Nacka - Folkungag	602	242	-361	-60%
Slussen - Nacka	307	303	-3	-1%

TABLE 3. Average travel times per vehicle (sec) for four major OD pairs in MEZZO with traffic through VISSIM area for old and new control strategies

Table 3 shows the average travel time per vehicle (in sec) for four selected OD pairs that have traffic which crosses the microscopic area (in VISSIM). The first OD pair “Nacka-Slussen (1)” is relatively close to the edges of the micro area, meaning that there are few alternative routes. The new signal control drastically improves the travel time for these vehicles (by 52% or 367 sec.) Even for the second OD pair “Nacka-Slussen (2)” which has an origin and destination located further from the entry and exit points to the microscopic area, the travel time per vehicle is improved substantially (by 51% or 397 sec.). The “Nacka-Folkungag” OD pair shows even larger (relative) improvement, 60% or 361 seconds. On the other hand, the OD pair in the opposite direction “Slussen – Nacka” shows no significant improvement in travel time per vehicle.

The congestion that builds up towards Nacka (from both the Nacka-Slussen OD pairs) with the old signal control crosses the boundary into Mezzo (as can be seen from figure 2) and causes large queues and heavy delays. This accounts for the larger differences in OD travel times than the differences observed inside VISSIM alone.

In a parallel project (MATSIS) VISSIM and the EC1-simulator were run standalone on a similar microscopic network as used in this paper. The preliminary results show larger improvements with the new signal control strategy than those presented in this paper. The average speeds increased with 39% (compared to 29% in this paper), the average delay per vehicle decreased with 62% (27% in this paper). The average stopped delay decreased with 49% (31% in this paper) and average number of stops per vehicle decreased with 53% (27% in this paper). Some of these differences can probably be attributed to the redistribution effects that are captured by the hybrid model in this paper, but not by the standalone application. However, the VISSIM network used in MATSIS is extended on the approach from Nacka, meaning that the queues that now spill over in MEZZO are captured in VISSIM, and therefore the effects in terms of speed, stops and delay per vehicle are larger since they take into account more queued vehicles in the old signal control case.

5. CONCLUSION

In this paper we discussed the development, implementation and application of a hybrid meso-micro model which applies micro simulations to areas of specific interest, while simulating a large surrounding network in lesser detail with the meso model. The hybrid framework presented in an earlier paper was adapted to allow for implementation in a commercial model. This hybrid model was interfaced with an adaptive signal controller simulator which reproduces the exact control behavior as is implemented in the field. Using this set-up the hybrid model was applied to a case study where two alternative signal control schemes for three intersections were evaluated, using VISSIM to simulate the area with the three signal controlled intersections and MEZZO to simulate the surrounding Stockholm network. The results show the improvements of the new control scheme, but more importantly, they illustrate the usefulness of the hybrid approach for such types of applications. While the local effects could have been studied using VISSIM standalone, the hybrid setting allowed the study of redistribution effects of the improved local conditions in the micro area, due to the improved control scheme. The results show that even though the improved control caused the attraction of more traffic through the micro area (higher flows), the net effect was still positive, with less delays, less stops and shorter travel times inside the micro area, and shorter travel times for the main OD pairs with traffic through the micro area.

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