Hybrid Mesoscopic-Microscopic Traffic Simulation

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Abstract

Traffic simulation is an important tool for modeling the operations of dynamic traffic systems. While microscopic simulation models provide a detailed representation of the traffic process, macroscopic and mesoscopic models capture traffic dynamics of large networks, in lesser detail, but without the problems of application and calibration of microscopic models. In this paper we present 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. We identify requirements that are important in order for a hybrid model to be consistent across the models at different levels of detail. These requirements vary from network and route-choice consistency to consistency of traffic dynamics at the boundaries of the micro and meso submodels. We propose an integration framework that satisfies these requirements. A prototype hybrid model is used to demonstrate the application of the integration framework and the solution of the various integration issues. The hybrid model integrates MITSIMLab, a microscopic traffic simulation model, and Mezzo, a newly developed mesoscopic model. The hybrid model is applied in two case studies. The results are very promising and support both the proposed architecture and the importance of integrating micro and meso models.

Keywords: Traffic simulation, Traffic models, Mesoscopic, Microscopic, Hybrid

1. INTRODUCTION

Traffic simulation has become very popular for modeling the operations of dynamic traffic systems. Traffic simulation models are 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, the application of micro simulation is not without problems. Due to the detailed nature of the 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. Finally, and due to the complicated structure of the models involved, calibration is not trivial. Furthermore, for these reasons and due to their complexity, microscopic models are usually applied to smaller networks and may suffer from boundary effects. On the other hand, macro and meso models usually have fewer parameters to calibrate and are less sensitive to errors in network coding or demand variations. However, 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.

The objective of the paper is to present a methodology for the systematic integration of meso and micro simulation models into a single hybrid model. Such a hybrid model has the advantages of both types of simulation since it combines high fidelity micro simulation in areas of particular interest, with meso simulation of a large surrounding area. Another advantage of the integration is that it reduces the computational requirements. Overall, integration enables the simulation of large scale networks, incorporating the effects of local micro phenomena, with increased accuracy and validity, while reducing the required data collection and calibration effort of the overall model.

The remainder of the paper is organized as follows. Section 2 identifies the main requirements for a successful hybrid simulation model. Section 3 introduces the integration framework and proposes solutions for the various issues and requirements identified in section 2. Section 4 presents results from two case studies that illustrate the consistency issues and the importance of integration. Finally, Section 5 draws conclusions and summarizes the paper.

2. MESO-MICRO INTEGRATION REQUIREMENTS

An important aspect in developing a hybrid meso-micro traffic simulation model is the identification and implementation of conditions for consistent interfaces between the meso and micro simulation components of the simulation model. These conditions range from structural compatibility issues in terms of modeling traffic flows in the two models, to compatibility of route choice.

Previous studies of dynamic hybrid models include Micmac *(7)*, Hystra *(8)*, *(9)*, and Micro-Macro link *(10)*. These models combine dynamic macro with micro simulation. They focus on compatibility issues that arise from combining two models that represent traffic flow at two different resolutions. The macro models represent traffic as continuous flows, while the micro models represent individual vehicles. The proposed approaches vary in how they address the problem of converting continuous flows into individual vehicles and vice-versa at the macro-micro boundaries. In *(7)* the micro model is adapted to fit a number of conditions regarding the fundamental diagrams, produced by the macro model, while in *(8)*, *(9)* first a micro model is derived from the LWR theory *(11)* *(12)*, in order to fit the macro model which is also based on the LWR theory. This model showed good equivalence, but was difficult to extend. The second model presented in *(8), (9)* is based on Newell's optimum velocity model *(13)*. In *(10)* the micro model (IDM) and macro model (GFT) are derived from gas-kinetic type differential equations.

However, restricting the micro model to fit the macro model, or deriving the micro model from macro equations, may limit the capability of the model since the micro-macro equivalence usually only holds during steady state flows. Since only the car-following model is derived or adapted to fit the macro model, important aspects such as lane-changing are not part of the equivalence, and neither is gap-acceptance and stochasticity of user behavior. It is not clear how these aspects can be introduced (although *(9)* shows how stochastic desired speeds can be introduced) while maintaining equivalency, and in *(7)*,*(8)* and *(9)* the use of 'transition cells' is reported to be necessary. Furthermore, the approach may constrain the type of car following models that can be used, as the range of multi-regime models such as MITSIMLab *(5)*, Aimsun *(14)* and Paramics *(15)*, as well as psycho-physical models such as Vissim *(6)* cannot be derived from macro models, nor can their steady state properties be theoretically derived.

The approach proposed here for the development of a hybrid model focuses on the integration of meso with micro models. Since meso models represent flow as individual vehicles, earlier problems of aggregating/disaggregating the flow are easier to deal with. The main requirements for the development of a micro/meso hybrid traffic simulation model include:

Consistency in route choice and network representation

One of the most basic conditions is general consistency of the two models in their representation of the road network, paths, and route choice. The route choice needs to be consistent to ensure that vehicles will make the same decision given the same route choice situation (pre-trip or en-route), regardless if they are in the micro or the meso model. This means also that the representation of the alternative paths needs to be consistent throughout the hybrid model, as well as the travel times (link costs).

Consistency of traffic dynamics at meso-micro boundaries

Besides the consistency of network representation, the consistency of traffic dynamics at the boundaries between the meso and micro submodels needs to be ensured. This means that traffic dynamics upstream and downstream of the boundaries need to be consistent. For instance, when a queue is forming downstream of the boundary point, and grows until it reaches the boundary, it should continue in the other submodel, upstream of the boundary, in a similar way as it would if the boundary had not been there.

Consistency in traffic performance for meso and micro submodels

The two submodels need to be consistent with each other with regard to the results they produce. Ideally, for those facilities that can be simulated sufficiently well by both models, the results, in terms of common outputs, such as travel times, flows, speeds, densities, etc, should be similar. This implies the need for consistent calibration of the two models.

Transparent communication and data exchanges

The submodels exchange large amounts of data conveying vehicle characteristics, and downstream traffic conditions. This requires an efficient synchronization and communication paradigm, and a design that minimizes the amount and frequency of data exchange. Otherwise the communication overhead may become very large. On the other hand, aggregation and disaggregation of information at the boundaries may introduce complications, and should thus be avoided (see *(7)*,*(8)*, *(9)*, *(10)*).

3. INTEGRATION FRAMEWORK

In this section we propose an implementation architecture that facilitates the consistency between the submodels and discusses alternative modeling approaches to meet the requirements identified in Section 2.

3.1 Architecture

Simulation models are in general a synthesis of a number of supply and demand models. Meso and micro models use different approaches to model traffic dynamics and different levels of aggregation for network representation. However, since they both use an individual vehicle-based representation of flow, they usually employ similar travel behavior models (e.g. route choice models). Hence, the route choice component should be shared by both models, and operate on the complete network graph, including both the micro and meso areas. The paths should be defined over this common network graph, and the link travel time database should cover the entire network, and also be shared by both models.

The proposed architecture consists of a module, outside the meso and micro models, that contains the common elements: 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.

<insert figure 1 here>

Figure 1a presents the proposed integration architecture. The travel behavior component in the common module uses the database that contains the complete network graph, link travel times and known paths for the entire network. Both the micro and meso models supply descriptions of their subnetworks, from which the network graph is constructed. Each time a vehicle makes a route choice (whether in micro or meso), the common module is consulted. For the common route choice module to operate properly, the meso and micro models need to update the travel time database regularly with the link travel times in their subnetwork.

The common module also includes the OD matrix for the entire network. To simplify the information exchange and facilitate a transparent data input interface, it is assumed that all origin and destination nodes in the network belong to the meso subnetwork. 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.

The above architecture is applicable in the case where the two simulation models to be integrated have an open architecture or are new models, developed with integration in mind. In integrating existing models, that are not as flexible, the implementation of the integration framework needs to be adjusted to minimize inter-model communication, and use functionalities that are implemented separately in each model in a consistent way. For example, the simulation models may have their own route choice models. In this case, consistent route choice behavior across submodels requires two conditions: a) route choice models with the same structure and parameters in the two submodels, and b) consistent path choice set (defined over the entire network). To maintain the required consistency in this case, the micro and meso networks are enhanced with the addition of virtual links that correspond to the paths in the remaining network.

More specifically 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, and uses them in the route choice like any other link in the network. Similarly the micro network is expanded with the addition of *micro virtual links* to the micro subnetwork. The virtual links allow the micro model to deal with en-route choice in the micro subnetwork. Since each path from an exit point in the micro network to a destination in the meso network is represented by a virtual link in the micro model, a change of route for a vehicle in the micro sub-network can effectively mean a different exit point into the meso network. There are no limitations in the framework regarding the number of virtual links, nor the recalculation of the virtual links due to changing traffic conditions.

The above considerations simplify the initial architecture considerably in the case where integration of existing simulation models takes place (Figure 1b). Under this architecture, and based on the OD matrix representation discussed earlier, the meso model is solely responsible for all pre-trip decisions, while en-route decisions are the responsibility of the respective subnetwork and paths *inside* the meso model. This architecture has a number of practical advantages compared to the initial one. While the initial architecture would be preferable in the case of a new meso-micro model, it would require large amounts of communication overhead when combining two existing models. With the above modifications this overhead is avoided.

3.2 Modeling for Consistency

Assuming a common network graph, the architecture proposed in section 3.1 ensures route choice consistency. However, several aspects still need to be addressed at the modeling level, especially at the interface between the micro and meso areas.

Network representation

Problems may occur if the level of detail in micro and meso subnetworks is not consistent. Networks for micro simulation include (almost) all roads in the area of study. On the other hand, meso networks are much larger and may include only a subset of the roads. When these networks are combined into a general network there are two problems: a) connectivity, and b) capacity at the interfaces.

The connectivity problem arises when not all links in one model (micro) are present in the other (meso) at the boundary of the two models (this may also affect the correct definition of paths over the entire network). For the same reason, the micro capacity at the boundary interface may be different than the meso capacity. This can lead to very biased results unless the level of network aggregation across the boundaries is both consistent and appropriate. Of course, an easy and practical solution to this problem may be to increase the level of detail in the meso subnetwork where it connects to the micro subnetwork, and maybe decrease the level of detail in the micro subnetwork, near the boundaries with the meso one.

Modeling traffic dynamics at meso-micro boundaries

The limited literature on hybrid simulation models focuses on aggregation/disaggregation issues between the macro and micro representations of traffic (see *(7),(8), (10), (16)*). In our case these issues are avoided by integrating two models that have a vehicle-based representation of traffic flows. However, other issues concerning the interfaces between the models remain. In principle, the main sources of potential inconsistencies at the interface between the meso and micro models are:

- Location of boundaries
- Queue formation and representation
- Vehicle attributes (i.e. determination of speeds and accelerations of vehicles crossing the micro/meso boundaries)

Location of boundaries. Due to the fact that the meso and micro submodels may represent links and intersections differently, the positioning of the boundaries between them should be carefully considered. Placing them at nodes in the overall network would imply that some of the legs of an intersection would be at meso and some at micro level. This creates the problem of having to deal with the intersection behavior (signal controlled or otherwise) at different levels of detail. For instance, gap acceptance models in the micro module require vehicles' positions, speeds and gaps in the opposing flows. This information though, is not typically available at the mesoscopic level. It is recommended therefore, that the boundaries be located in the middle of links, with exactly one entry and one exit segment.

Queue formation and representation. The placement of boundaries is also dependent on the homogeneity of traffic conditions. Typically micro models, due to their level of detail, represent lane-specific queues. Meso models on the other hand, usually do not have lanes. If this is the case, a queue on one lane in micro, even if the other lanes remain open, will block the boundary node completely, unless the exchange of vehicles at the boundary is taking place properly. The virtual links in the meso subnetwork play an important role in solving the problem of inconsistent queue representation. Virtual links that represent paths that can only use the blocked lanes will be blocked, while virtual links representing paths that use open lanes will have available capacity and allow the proper advancement of the corresponding vehicles.

Crossing vehicle attributes. The attributes of the vehicles as they cross the boundaries need to be properly determined 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 (over that specific boundary) again. 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*.

The variables that need to be assigned values at the entry of a vehicle from the meso into the micro models are usually: lane, time-headway to the vehicle in front, speed and acceleration. From the meso model the time-headway is determined, but not the speed, acceleration or lane. Based on the type of vehicle and the vehicle's path, a set of feasible lanes is specified. The vehicle is loaded on the lane with the largest available headway (space). The speed assigned to the vehicle according to the following algorithm:

- Regime 1 (bound traffic): $t_1 < t_h <= t_2$
  $V = V_{front}$
- Regime 2 (partially bound traffic): $t_2 < t_h <= t_3$
  $\alpha = (t_h - t_2)/(t_3 - t_2)$
  $V = \alpha * V_{desired} + (1-\alpha) * V_{front}$
- Regime 3 (unbound traffic): $t_h > t_3$
  $V = V_{desired}$

Where,

t_i = threshold, to be calibrated
t_h = time headway (s)
V = speed (km/h)
V_{front} = speed of vehicle in front (km/h)
$V_{desired}$ = desired speed (km/h)

The above approach was tested with actual data in *(17)*. Measurements of speeds and time-headways on an urban freeway in Stockholm show high correlation of speeds between consecutive vehicles on the same lane, in the case of small headways (t_1 = 0.5 seconds, t_2 = 2.5 seconds). This correlation decreases with increased time headways, and remains at a constant low level beyond t_3 = 7.5 seconds. In almost all micro models, an initial acceleration rate of 0 m/s^2 is assigned to the vehicles that enter the network. The assignment of zero acceleration to the vehicles crossing the micro boundary suffices for the hybrid model as well.

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. In the first instance 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, and 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 idea can also be found (in a slightly different form) in *(8)* and *(7)*. An obvious refinement is to use lane-specific virtual vehicles.

3.3 Communication/Synchronization

The meso and micro models need to communicate with each other to hand over vehicles that cross the boundaries, and inform each other of traffic conditions downstream of the boundaries, so that traffic upstream can react to these. Hence, in order to facilitate the proper modeling of the traffic dynamics at the interfaces, as outlined above, the following information is exchanged between the submodels:

1. vehicles passing the boundaries between the models and their characteristics
2. link blocking/unblocking information
3. density on micro segments
4. information for virtual vehicles (speed and entry time of vehicle that last crossed the border)

4. CASE STUDIES

Two case studies are used to illustrate the points made in this paper. The consistency issues and their resolutions are discussed through a case study with a small artificial network. The importance of integration in the quality of the results is illustrated in a second case study using an actual network from Stockholm. The hybrid model used in the case studies was developed using two simulation models: MITSIMLab and Mezzo.

MITSIMLab is a high fidelity micro model, which has been applied in a number of studies, and has been calibrated and validated in both USA and Sweden *(18, 19)*. Mezzo is a new event-based mesoscopic model that was developed in the context of this research *(20)*. A network in Mezzo consists of nodes and links. The links are characterized by the number of lanes and length. Each link has a speed/density function associated with it, that determines the traversal speed of vehicles entering the link, given the density at the time of entry. At the nodes, one stochastic queue-server for each turning movement regulates the transfer of vehicles from one link to another. The queue at the downstream end of the link consists of vehicles that are ready to exit (given their entry time and traversal speed), and occupies space. The density on the part of the link *not* occupied by the queue (*running part)* is used in the calculation of the traversal speeds. Queues blocking upstream of a turning movement can block access to other turning movements, if they grow beyond a predetermined length.

The propagation of queue-fronts is modeled based on the shockwave theory *(11), (12)*. The shockwave speed of the queue front is calculated for cases in which a queue dissipates in the downstream segment. When the dissipation reaches the current segment, the flow and density in the downstream segment and current segment are used to calculate the propagation speed of the start-up shockwave. In addition, the downstream density is used to determine the speed of the vehicles once they start moving towards the stopline. Using these two speeds, the delay to each vehicle is calculated.

The two submodels communicate via PVM *(21)*, which makes it possible to run Mezzo and MITSIMLab on different computers. Since Mezzo is event-based, and has thus a continuous representation of time, the message passing is also used for synchronizing with the micro time-steps. A message with the relevant information for Mezzo is sent at each MITSIMLab time-step, and upon receipt, Mezzo sends back a message with the relevant information for MITSIMLab. These messages from MITSIMLab are therefore treated as external events, and are processed just like any other event.

4.1 Case Study I

We will illustrate the behavior of the hybrid model using a simple network operating under incident conditions. In the first case the incident takes place in the micro part of the network and in the second in the mezzo part. We focus our discussion, specifically on the way queue build-up and dissipation propagates across the boundary, both in the meso-to-micro and micro-to-meso direction.

The network consists of a single two-lane road that is 5 km long, divided into 10 segments of 500 meter (Figure 2). The first five segments are within Mezzo, followed by two segments in MITSIMLab, and finally three Mezzo segments.

<insert figure 2 here>

The free flow speed is 100 km/h. A constant demand of 3000 veh/h is applied for a simulation time of 1 hour (3600 seconds). The locations of the incidents are indicated in Figure 2. The first scenario has the incident on the boundary between segments 5 and 6 in MITSIMLab, and the second on the boundary between segments 8 and 9 in Mezzo. The incidents occur 20 minutes into the simulation and completely block the link for 5 minutes. Mezzo was calibrated using data obtained from MITSIMLab, run independently on the same network, under a variety of demand loads. The parameters in Mezzo that require calibration include the capacity of the servers at the nodes and the parameters of the speed-density relationship used to determine the speed of the vehicles. *(22).*

<insert figure 3 here>

Figure 3a shows the cumulative outflow (veh/lane) for segments 0 to 5 under the first scenario. The cumulative flow shows that the propagation of changes in flow in both queue build-up and queue-dissipation is smooth and consistent across the meso-to-micro and micro-to-meso boundaries. As the queue grows it starts blocking upstream segments as shockwaves start traveling upstream. Figure 3b illustrates the evolution of density over time in the five segments of interest. The density increases in segment 5 (MITSIMLab) after the incident takes place. The queue reaches the boundary with the mezzo segment 4 approximately when the incident is cleared, causing the queue on segment 5 to dissipate. However, the end of the queue still exists and that causes the density in segment 4 to remain high for some time, also causing upstream segments to get blocked. As in the cumulative flow plot, it can be observed that queue formation and dissipation behave properly over the boundaries. There are some differences between the Mitsim and Mezzo segments. The queue dissipation shockwave propagates faster in Mezzo than in Mitsim. This is possibly due to the simplified representation of acceleration and driver reaction delay time in Mezzo.

It can also be noted that when the queue front reaches the queue back on the last congested segment (segment 1), it causes an increase in the density in segment 2. This may be a result of the simplified traffic dynamics representation in the Mezzo model, which does not take into account the vehicles that approach the end of the queue but never come to a complete stop. Because of this simplification, the outflow of this segment is larger, resulting in a second 'bump' in the density of the downstream segment. In general, the results indicate that the queue propagation and dissipation behavior is consistent across the Mezzo-MITSIMLab boundary.

In the second scenario a similar type incident is introduced at the exit of segment 8 in Mezzo. In this scenario queue behavior similar to scenario 1 (Figure 3) occurs. One difference that was observed is the steep increase of the outflow from (Mezzo) segment 8 at the end of the incident, whereas the increase in flow on (MITSIMLab) segment 5 is smoother and slower. This can be explained by the fact that the shockwave theory which is used for modeling the queue dissipation in Mezzo, assumes immediate changes in speed, while the vehicles in MITSIMLab are bound to their acceleration limits (and reaction times). Another reason may be the quality of the calibration of the Mezzo speed/density function.

4.2 Case Study II

The objective of the second case study is to compare the accuracy of the results of the hybrid model against actual measurements (for more details about this case study see *(22)*). The hybrid model (MiMe) is used to simulate the operations on a mixed freeway/urban network in the north of Stockholm (Brunnsviken). MITSIMLab has been calibrated and validated independently for the same network (see *(18)*).

<insert figure 4 here>

The network (Figure 4) is divided into the meso part in the north, which consists mainly of freeways, and micro part in the south, which consists of a number of complex intersections with coordinated signal control and a large roundabout. The area is highly congested during the studied period, which is the morning peak, 6:45 – 9:00 a.m. Sensor count data from 12 locations across the network, averaged over 15 minute intervals, was available from May 2000. The OD matrix used for this case study was estimated in *(18).*

The performance of the hybrid model is compared against MITSIMLab and Mezzo using the RMSNE (Root Mean Squared Normalized Error) relative to observed flow values and Theil inequality coefficient U(*(23), (24)*). The U error proportions U^M, U^S, and U^C are also used to measure the systematic (bias), variance, and non-systematic (covariance) proportions of the errors. Table 1 summarizes the results. *MITSIMLab* corresponds to the results of the application of MITSIMLab alone, *Mezzo* to the results of the application of Mezzo alone, and *Hybrid* to the results of the application of the integrated model (MiMe).

<insert table 1 here>

The values indicate that, as expected, MITSIMLab performs best. According to the RMSNE values, the hybrid model (MiMe) performed better than Mezzo alone, due to the fact that the signal controlled portion of the network is now simulated at microscopic detail. The Theil U value indicates that the Mezzo model has a larger systematic error than MiMe. To further explore the nature of the differences, Table 1 reports the RMSNE for sensors located in different parts of the network (Meso network is the part of the network modeled by Meso in the hybrid model, and Micro network is the part of the network modeled by MITSIMLab in the hybrid model). The part of the network modeled by MITSIMLab in the hybrid model application is very congested and contains a number of complex signalized intersections. The results clearly illustrate the importance of the more detailed representation. Not only the accuracy of the simulation improves in the micro network but also in the meso network, presumably due to better flow propagation.

Finally, as expected the computational time for MiMe is far superior compared to the computational time required to model the network using MITSIMLab (about 5 times faster). This difference is expected to grow as the size of the network increases.

5. CONCLUSION

Micro and meso traffic simulation models have different strengths and weaknesses. While micro models provide a more detailed representation of the traffic process, meso models are able to capture traffic dynamics of large networks, in lesser detail, but without the data requirements and other application problems of micro models. In this paper we discussed the requirements for the development 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.

We proposed an integration framework that satisfies the integration requirements, and discussed a prototype hybrid model which integrates MITSIMLab (micro) and a newly developed meso simulation model. In a small case study aspects of consistency of traffic dynamics across boundaries of the individual models were demonstrated. The importance of hybrid modeling for the quality of the results was illustrated in a second case study using an actual network from Stockholm. The results indicate that by modeling specific parts of the network in microscopic detail, the quality of the simulation results improve. In addition, the data preparation, calibration efforts, and computing time are significantly reduced.

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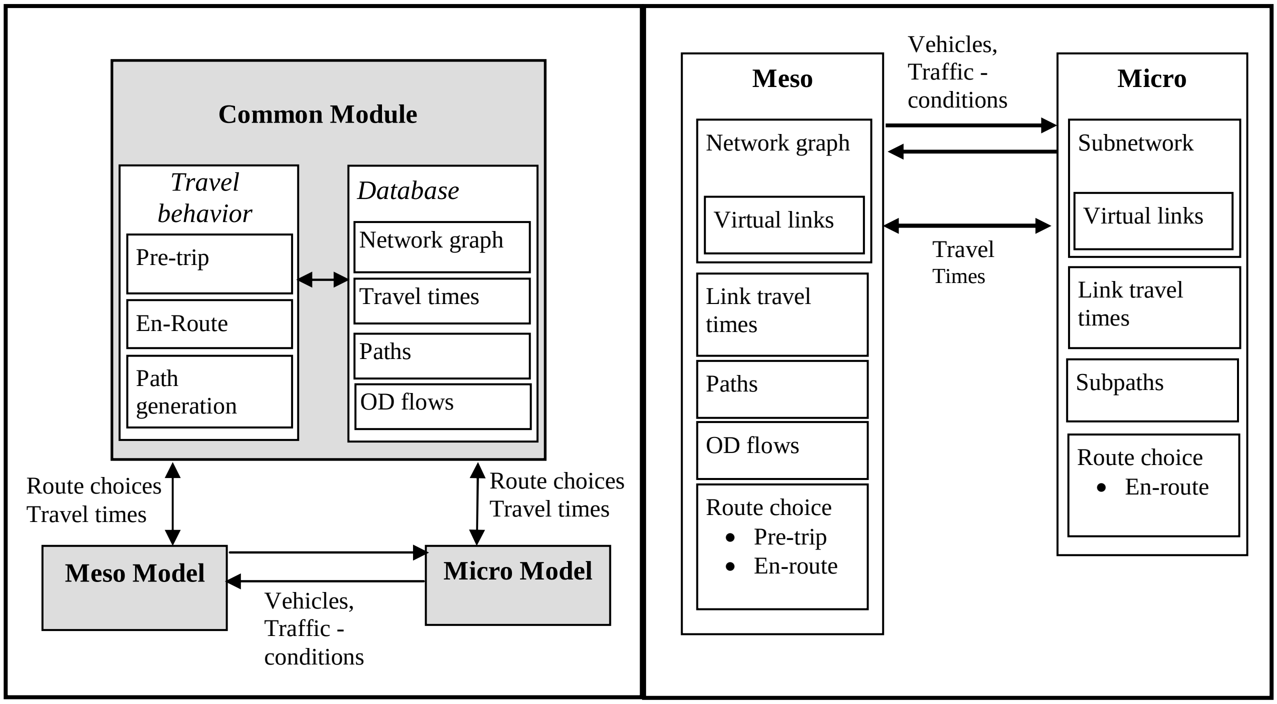
TABLE 1 Results of Case Study II on all three models.

	MITSIMLab	Mezzo	Hybrid (MiMe)
RMSNE			
Entire network	12%	16%	15%
Meso network	10%	13%	11%
Micro network	14%	18%	17%
Theil U	0.051	0.055	0.054
U^M	0.001	0.147	0.075
U^S	0.010	0.002	0.017
U^C	0.989	0.852	0.909



(a) Generic Integration Architecture **(b) Simplified Integration Architecture**

FIGURE 1 Integration Architecture

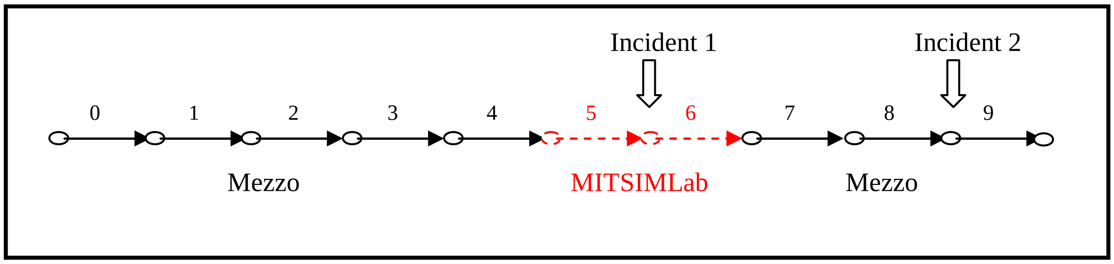
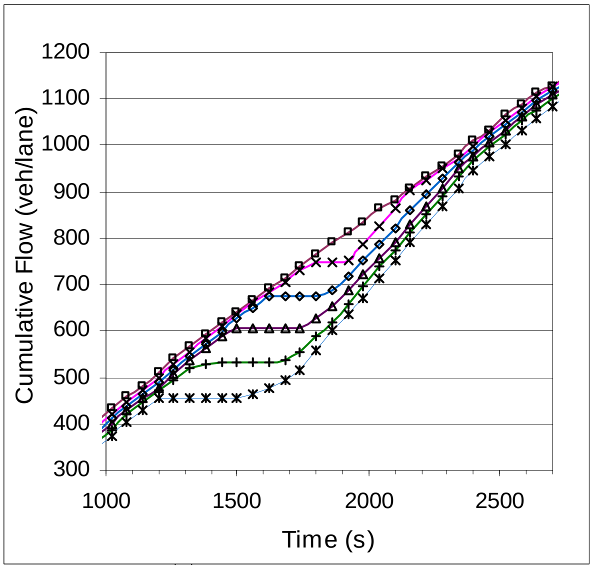
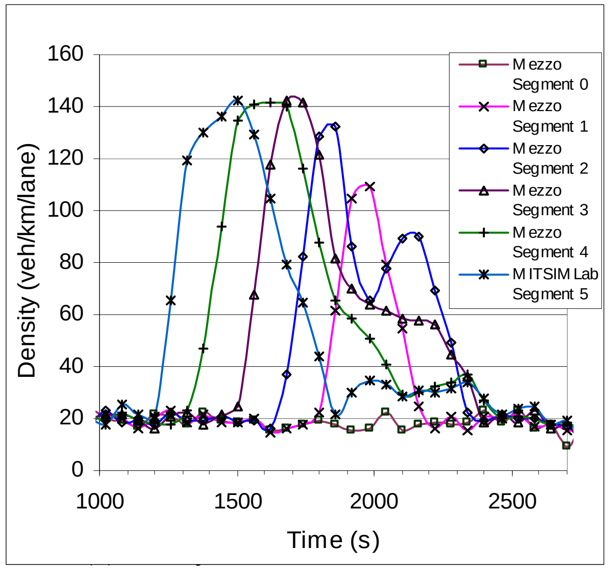


FIGURE 2 Test network





(a) Cumulative flow **(b) Density over time**

FIGURE 3 Case Study I results

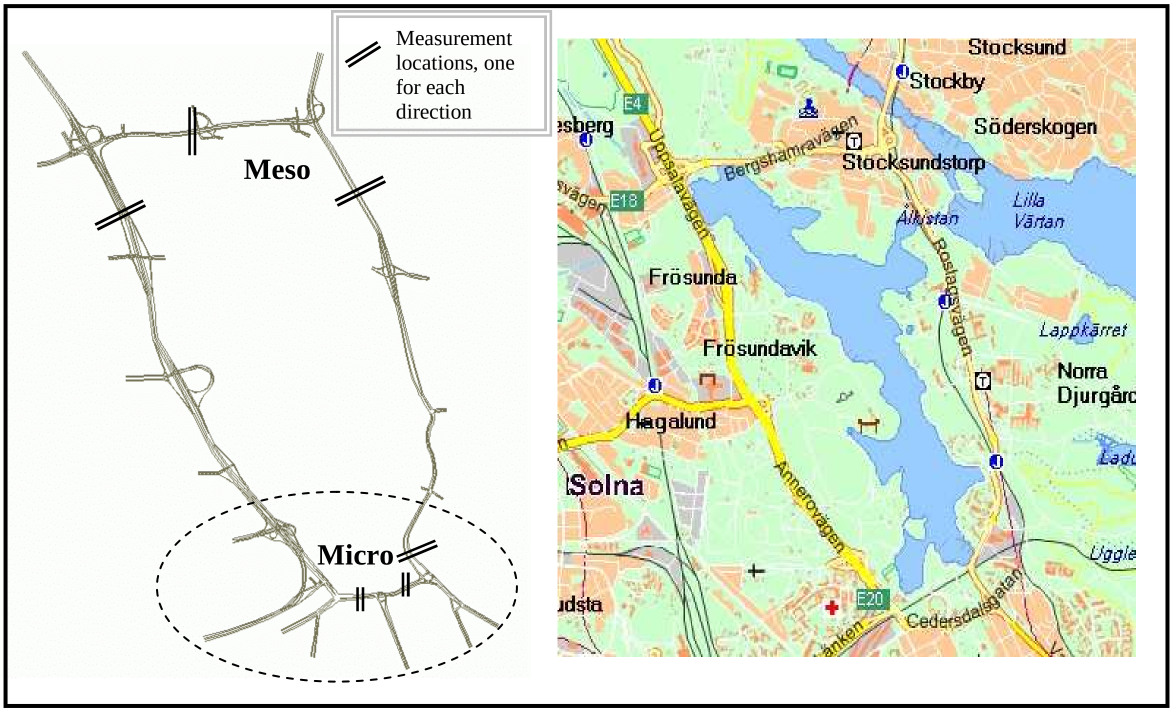


FIGURE 4 Application of Hybrid model (MiMe) on Brunnsviken / Stockholm network.