Hybrid Traffic Simulation Models:
Vehicle Loading at Meso – Micro Boundaries

Wilco Burghout
wilco@ctr.kth.se
Assistant Professor
Center for Traffic Simulation (CTR)
Royal Institute of Technology, SE-100 44 Stockholm, Sweden

Haris N. Koutsopoulos
haris@coe.neu.edu
Associate Professor
Department of Civil and Environmental Engineering
Northeastern University, Boston, MA 02115-5000, USA

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Wilco Burghout[1]
Haris N. Koutsopoulos[2]

Abstract. *Traffic simulation models, especially microscopic, are becoming popular and used to address a wide range of problems, from planning to operations. However, for applications with large scale networks microscopic models are not practical because of input data and calibration requirements. Hybrid models, that combine simulation models at different levels of detail have the potential to address these practical issues. The paper presents a framework for implementing meso-micro hybrid models that facilitate consistent representation of traffic dynamics. Furthermore, the paper examines in detail an important element that impacts the consistent representation of traffic dynamics, the loading of vehicles from the meso to the micro model. A new loading method is presented that shows superior performance compared to existing approaches. The method is useful not only in the context of hybrid models, but also for microscopic models on their own. A case study illustrates the importance of the method in improving the fidelity of both hybrid and pure microscopic models.*

1. Introduction

While microscopic traffic simulation is becoming ever more popular, especially in the evaluation of advanced traffic management systems and ITS, the amount of effort needed for model calibration and the preparation of input data often inhibits its use on large networks. Recently, hybrid mesoscopic-microscopic models have appeared (Burghout, 2004; Burghout, Koutsopoulos, and Andreasson, 2005; Yang and Morgan, 2006; Shi and Ziliaskopoulos, 2006) that allow for detailed microscopic simulation of specific areas of interest, while simulating the remaining areas in lesser detail on mesoscopic level. Since mesoscopic simulation has a more aggregate representation of the roadway and the vehicle interactions, it requires much less effort in calibration and preparation of input data (especially coding of the road network). In addition, a number of hybrid macroscopic-microscopic models have appeared recently (Bourrel and Lesort, 2003; Magne, Rabut and Gabard, 2000; Poschinger, Kates and Meier, 2000; Espie, Gattuso and Galante, 2006; Mammar, Lebaque and Haj-Salem, 2006).

Development and implementation of hybrid models that combine traffic simulation models at different levels of detail require the resolution of a number of issues, some of them related to the interaction of the two models at their boundaries. Important among those issues is the consistency in traffic dynamics at the meso and micro network boundaries.

The objective of this paper is twofold: to a) present a general framework for the implementation of hybrid simulation models that satisfies the various integration requirements; and b) discuss in detail one important aspect that has serious implications for the validity of simulation models in general and hybrid models in particular. This aspect is the mechanism used to load vehicles arriving from the mesoscopic area into the microscopic area, and affects the consistency of traffic dynamics at the meso-micro boundaries.

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[1] Assistant Professor, Center for Traffic Simulation (CTR), Royal Institute of Technology, SE-100 44 Stockholm, Sweden, wilco@ctr.kth.se

[2] Associate Professor, Department of Civil and Environmental Engineering, Northeastern University, Boston, MA 02115-5000, USA, haris@coe.neu.edu

The remainder of the paper is organized as follows. Section 2 discusses important requirements for hybrid models of high fidelity and presents a general framework for their implementation. Section 3 looks into modeling traffic dynamics at the micro-meso boundary in more detail. Section 4 discusses issues related to existing vehicle loading mechanisms and proposes a loading mechanism that alleviates the negative impact of prior methods. The latter problem is important not only in the context of hybrid simulation models but also microscopic simulation models on their own. Section 5 illustrates the impact of the loading mechanism through a case study with a small network and section 6 concludes the paper.

2. Hybrid modeling framework

The main requirements that the integration of micro/meso models needs to satisfy in order to develop reliable hybrid models include:

Consistency in network representation: One of the most basic conditions is general consistency of the two models in their representation of the road network, especially at the boundaries between the two models. Consistent network representation has important implications for capacity determination, and hence impacts traffic dynamics at the boundaries between the models. Furthermore, it impacts the links included in each model and hence, the consistency with respect to route choice as discussed below.

Consistency in route choice representation: One of the most important conditions is consistency of the two models in their representation of paths, and route choice alternatives. The route choice needs to be consistent across the models 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 the boundaries need to be consistent. For instance, when a queue is forming downstream the boundary point, and grows until it reaches the boundary, it should continue in the other submodel, upstream 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.

Figure 1 shows a general hybrid simulation framework (Burghout, Koutsopoulos and Andreasson, 2005) that facilitates the resolution of the issues discussed above. The travel behavior component in the common module uses the database that contains the complete network representation, 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 representation is constructed. Each time a vehicle makes a route choice (whether in micro or meso), the common module is invoked. 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 subnetworks.
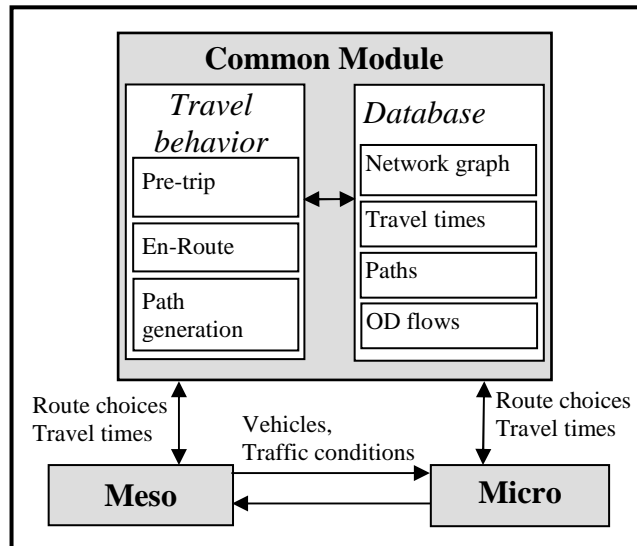
Figure 1. Hybrid simulation framework

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 not 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 model contains the entire network and route representation, by representing the paths inside the micro, from entry nodes to exit nodes, as *virtual links*. These virtual links are then used as part of the meso network description, so that the meso model choice can provide consistent route choice across the submodels. This issue is discussed in more detail in Burghout, Koutsopoulos and Andreasson, 2005 and Burghout, 2004.

3. Modeling traffic dynamics at meso-micro boundaries

Consistency with respect to traffic dynamics at the boundaries of the two models is critical. The limited literature on hybrid simulation models focuses on aggregation/disaggregation issues between the macro and micro representations of traffic (Bourrel and Lesort, 2003; Magne, Rabut and Gabard, 2000; Poschinger, Kates and Meier, 2000; Espie, Gattuso and Galante, 2006; Mammar, Lebaque and Haj-Salem, 2006). In the case of meso/micro models these issues are avoided since the integration involves two models that both 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.

One very important aspect that relates to the questions raised above is the loading of vehicles from the meso to the micro model. Vehicle loading in hybrid and microscopic simulation models comprises the generation of *initial values* for state *variables* such as headway and speed. This is different from the correct setting of *parameters* such as desired speed, which are static inputs, whereas state variables vary continuously describing the state of the vehicles.

4. Vehicle loading

When vehicles enter the microscopic network, the initial values for speed and headway need to be in accordance with each other and with the traffic situation downstream (and upstream). Otherwise immediate deceleration (or acceleration) will occur, affecting the traffic conditions upstream. Correct vehicle loading is crucial in a hybrid model since the artificially created disturbances propagate upstream and cause shockwaves in the mesoscopic model. It is equally important for standalone microscopic simulation models, since it affects the capacity at the entrance of microscopic networks. This is all the more important since in most applications of microscopic models the vehicles are loaded at links, rather than at centroids.

The issue of vehicle loading in microscopic models has been largely neglected until now, and publications and documentation of microscopic traffic models provide little or no information on how this issue is dealt with. The fact that the loaded vehicles are at the entrance of the network makes it difficult to observe errors in the loading mechanism since their immediate deceleration (or acceleration) does not cause an observable disturbance behind them. However, as will be shown in this paper, they do cause a drop in capacity at the entrances to the network, and therefore may affect the simulation results by prohibiting the loading of traffic at high volumes, or even cause distortion in the calibration process if other parameters are adjusted to compensate for the erroneous loading procedure. In short, incorrect vehicle speeds at micro-meso boundaries or micro origins lead to:

- excessive decelerations and accelerations
- volatility and delayed vehicle entry
- reduced capacity at entry points
- unnecessary turbulence and shockwave propagation upstream the meso component of hybrid models.

Vehicle loading in existing microscopic models

Although, details regarding the loading mechanism in existing micro simulation models are sketchy we present the default loading method used in two state of the art models, MITSIMLab (Yang, Koutsopoulos, and Ben-Akiva, 2000), and VISSIM (PTV, 2005).

MITSIMLab. The vehicle loading in MITSIMLab consists of lane selection and speed assignment componets. The lane selection depends on lane permissions (e.g. bus lanes), the continued path of the vehicle (so that it will not have to immediately change lane to continue its path) and available space on lanes. Of the 'acceptable lanes' the lane with the most space is selected. The speed of the loaded vehicle is set based on the vehicle's desired speed, the average segment speed and the entry queue length (see Figure 1). If the entry queue is 0 (no vehicles waiting to enter) the vehicle is loaded with its desired speed. When the entry queue grows (due to vehicles not being able to enter at the rate they arrive) the vehicle is loaded at a speed approaching the segment speed. The problem that this method may cause is that in congested situations, vehicles may be loaded at much higher speeds than the vehicles in front, causing immediate deceleration. This is expected to cause turbulence and shockwaves, and result in a reduced capacity for entry links.
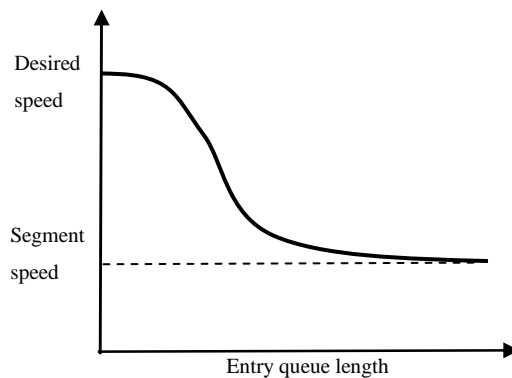

Figure 1. Vehicle loading speed in MITSIMLab

VISSIM. As in MITSIMLab, the lane selection in VISSIM depends on lane permissions and the available space headway, where the acceptable lane with the largest space headway is selected. The speed of the loaded vehicle in VISSIM is a function of the vehicle's desired speed, the speed of the vehicle in front (on the selected lane) and the space headway to the vehicle in front. If the front vehicle is beyond the look-ahead distance of the vehicle to be loaded, the speed of the loaded vehicle will be its desired speed. If the distance to the vehicle in front is 0, in theory the vehicle would be loaded with the same speed as the vehicle in front (provided that the vehicle in front has a lower speed than the loaded vehicle's desired speed). However, the vehicle to be loaded will not be able to enter the network if the space headway is smaller than a predefined safe distance. So in practice the vehicle will usually be loaded at a speed somewhat higher than that of the front vehicle. While this method will prevent extreme decelerations at the entry, it will still induce slight shockwaves due to the fact that in saturated conditions, most entering vehicles will have a speed that is somewhat higher than the speed of the vehicle in front and therefore always decelerate upon entry (see Figure 2).
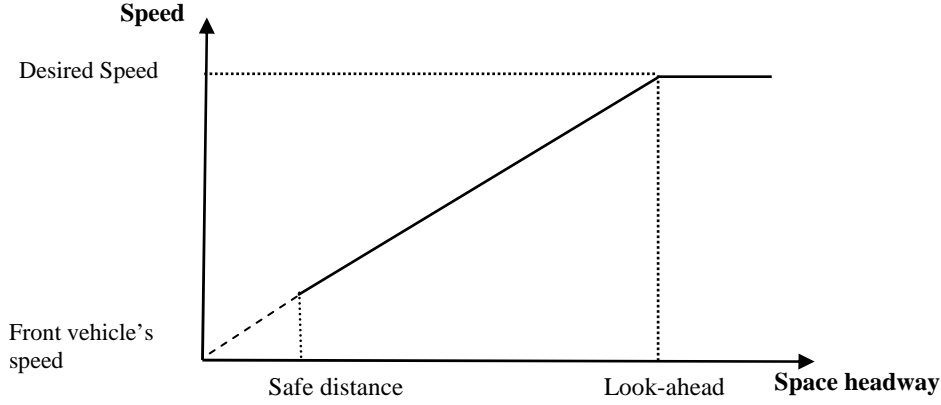
Figure 2. Vehicle loading speed in VISSIM

Proposed loading method

We propose a new loading method that aims at loading vehicles in a way that is more consistent with their behavior when they enter the network. In microscopic simulation models the car-following is one of the main models used to move vehicles in the network. Typical car-following models relate the acceleration of a vehicle to the behavior of the surrounding vehicles, especially the speed of, and the distance to the leading vehicle. The proposed method assigns speed to the vehicles entering the network (either loaded at the origin, or transferred from the mesoscopic part of the network) using a multi-regime approach based on the time headway between the entering vehicle and its leading vehicle (in the same lane):

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

where,

V:	assigned initial speed,
V_{front}:	speed of the vehicle in front (in the same lane),
$V_{desired}$:	vehicle's desired speed,
t_h:	time headway to the vehicle in front (in the same lane).
α:	parameter (0,1] that interpolates between the desired speed and the speed of the leading vehicle. If $V_{front} > V_{desired}$, $V=V_{desired}$.
$t_{i,}$:	time headway thresholds, determined/calibrated from field data, $i \in \{1, 2, 3\}$.

The time headway from the leading vehicle is defined as the time that has passed since the vehicle in front was at the loading point, *assuming it had its current speed*. This means that in case of queue build up and propagation towards the entry point, the vehicle in front is likely to have decelerated since entering, and therefore the time headway may be slightly overestimated.

The above loading mechanism is supported by empirical data. On the E4 motorway (Essingeleden) in Stockholm, individual speed and time headway data was collected (by the Swedish National Road Administration) using high fidelity microwave detectors, using one detector for each lane. During the measurement period the flows varied between 800 and 1700 veh/h/lane.

The measured speed and time headway data was grouped into time headway classes of 1 second each, i.e. one class for vehicles arriving with time headways of 0 – 1 seconds, one class for 1 – 2 seconds etc. Figure 3 illustrates the correlation coefficient between speeds of consecutive vehicles as a

function of their time headway. A clear trend can be observed from the data, with very high correlation for the vehicles following at close time headways (classes 0 – 1, 1 – 2, and 2 – 3 seconds). As expected, for the 3 – 4, 4 – 5 and 5 – 6 second time headway classes the correlation coefficients decrease. It should be noted that the sample size of the classes for longer time headways is much smaller than for the classes for short headways.
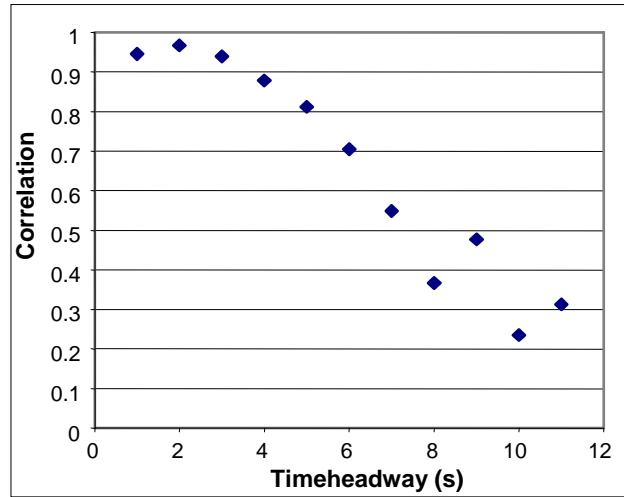

Figure 3. Consecutive vehicle speed correlation

Figure 4 compares the actual speeds of two consecutive vehicles in the two extreme classes 1 – 2 seconds and 7 – 8. The scatter plots clearly show the high correlation in the 1 – 2 second group, compared to the correlation in the 7 – 8 second group.

a) 1 – 2 second group b) 7 – 8 second group
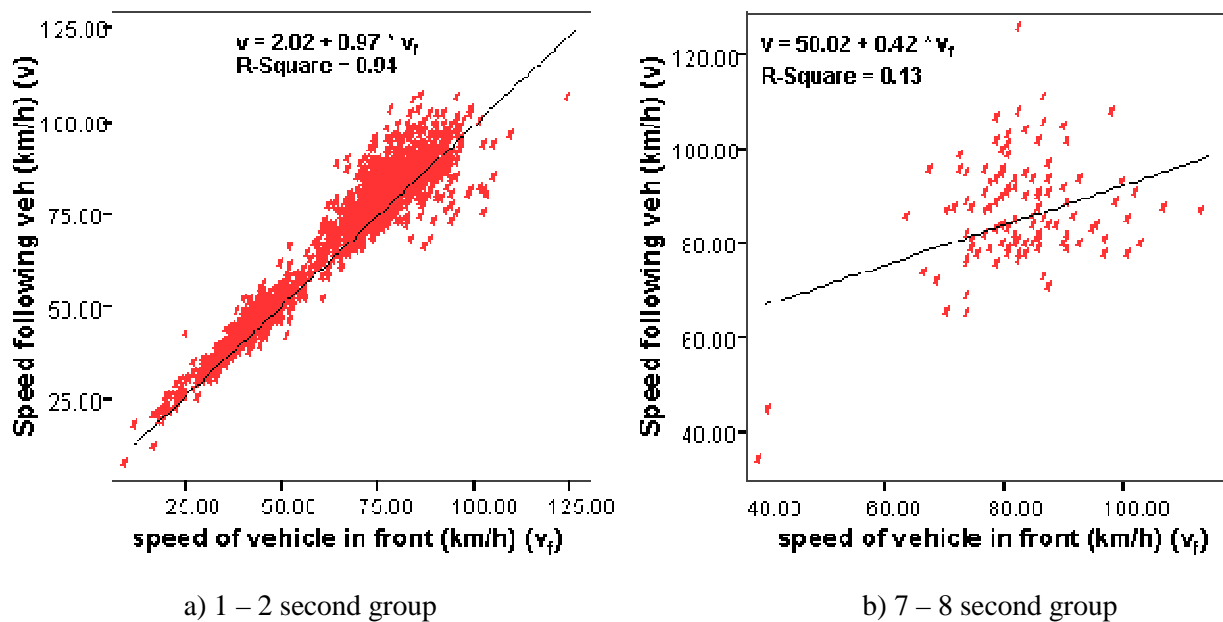
Figure 4. Scatter plots of consecutive vehicle speeds

Based on the above data, the following default headway thresholds for the proposed loading method have been estimated:

- $t_1 = 0.5$ seconds (minimum headway parameter)
- $t_2 = 2.5$ seconds
- $t_3 = 7.5$ seconds

5. Case study

We demonstrate the importance of loading using two state-of-the-art microscopic traffic simulation models, MITSIMLab (Yang, Koutsopoulos, *et al.,* 2000) and VISSIM (PTV 2005). The impact on the performance of a hybrid model is also demonstrated using the hybrid model MiMe (Burghout, 2004) that combines MITSIMLab and the mesoscopic model MEZZO (Burghout 2004).

A small, linear network is used to demonstrate the impact of the loading mechanism. The network in Figure 5 is used to evaluate the performance of each simulation model (MITSIMLab and VISSIM).
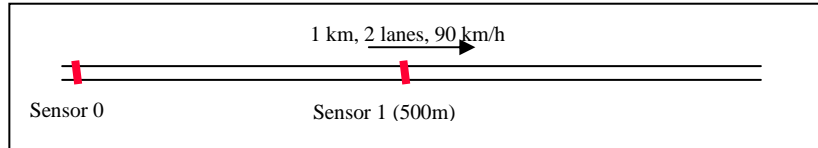
Figure 5. Test network for MITSIMLab and VISSIM alone

The network is loaded with a time dependent demand that increases slowly from t = 0 – 1800 sec and creates relatively high flows from t = 1800 – 2400 sec, after which it decreases gradually (Figure 6).
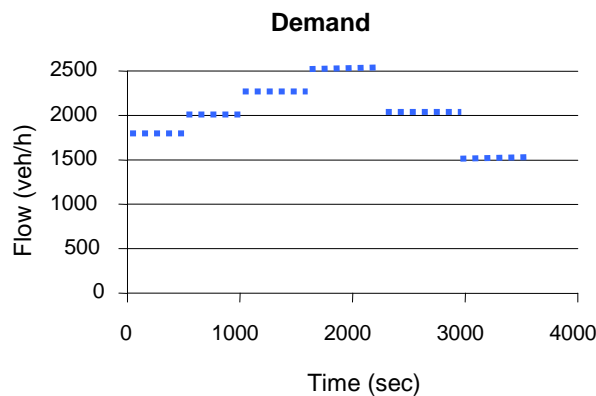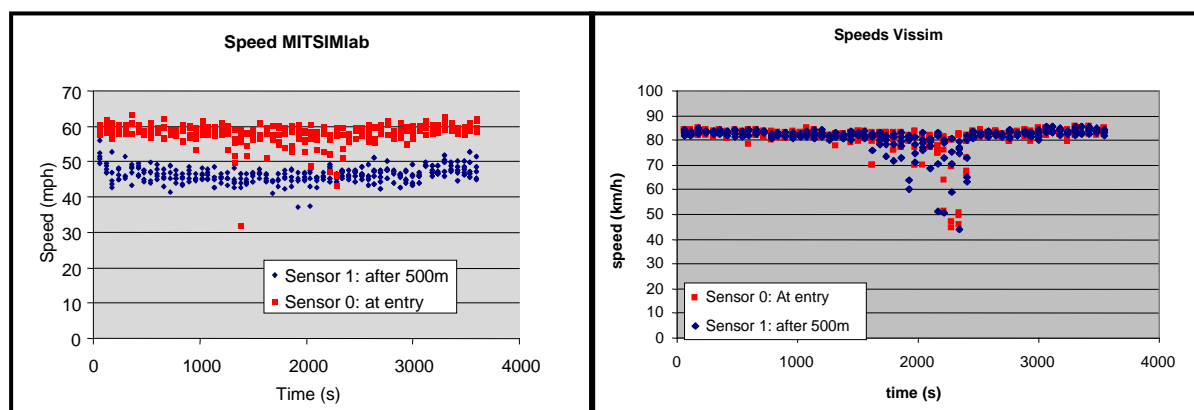

Figure 6. Demand profile

The importance of the loading method is best illustrated by the distribution of speeds at sensor locations 0 (at the entry) and 1 (500 m downstream). Figure 7 shows the speed at these locations for MITIMSLab (7a) and VISSIM (7b) when the default loading mechanism is used.

a) MITSIMLab   b) VISSIM

Figure 7. Impact of default loading mechanism

The loading in MITSIMLab clearly indicates a number of problems, especially since the vehicles enter the network at rather high speeds. Although the speeds in VISSIM appear more consistent between the sensors, problems still exist with respect to the loading of vehicles in VISSIM as well. Figure 8 shows the minimum acceleration (i.e. max deceleration in absolute value) of the vehicles entering the

9

network in VISSIM. Ideally, the minimum accelerations over sensors 0 (at entry) and sensor 1 (after 500m) should be similar. However, Figure 8 illustrates that the minimum accelerations over sensor 0 are much greater than those over sensor 1, indicating that some friction is caused by the vehicle loading. This has implications on the number of vehicles the simulator is able to load on the network (capacity at entry points). During the peak demand period (1800 – 2400 sec) 18 vehicles were not able to enter the network.
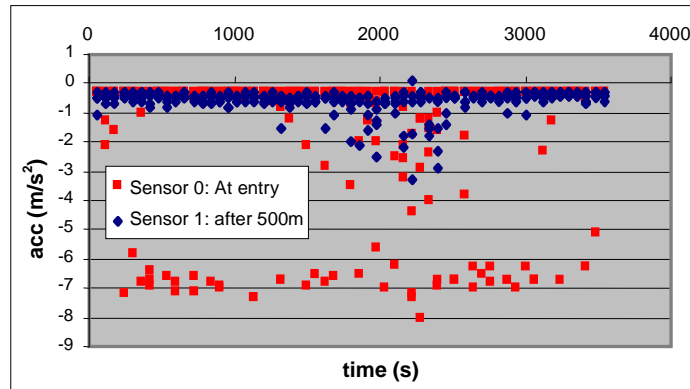

Figure 8. Minimum acceleration of vehicles in VISSIM.

The proposed loading mechanism was implemented in MITSIMLab. Figure 9a shows the speeds of the vehicles over sensors 0 and 1 with the new loading mechanism. Figure 9b shows the corresponding average accelerations, during the first 20 sec after vehicles enter the network (at 0.1 sec intervals), and compares them to the acceleration of the vehicles with the original loading method.
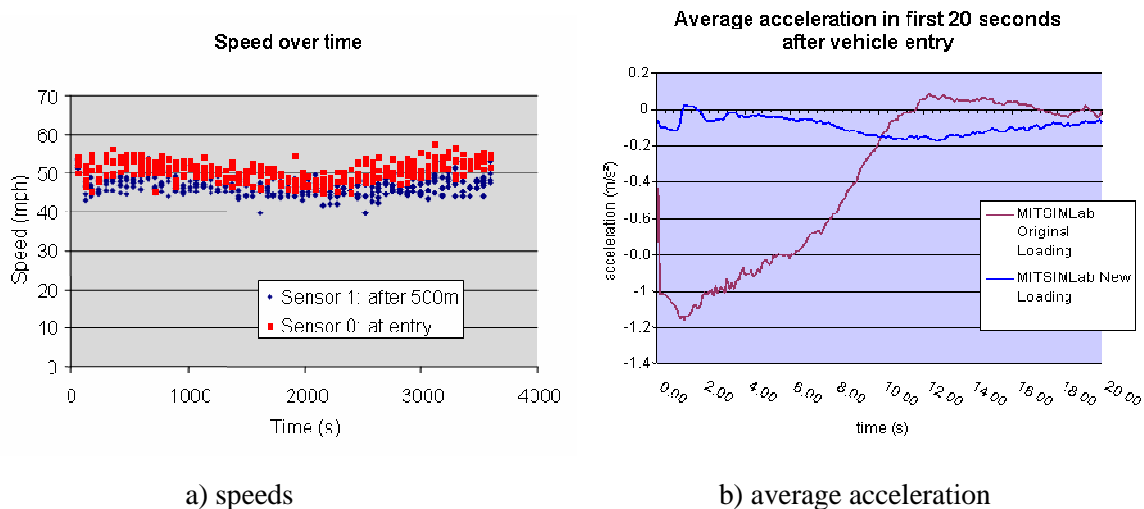
a) speeds   b) average acceleration

Figure 9. MITSIMLab: Impact of proposed loading

As discussed before, the original loading method in MITSIMLab generates initial speeds (sensor 0) that are too high for the time headway and the traffic conditions immediately downstream (see Figure 7a), causing large decelerations of the entering vehicles (see Figure 9b) Because of the resulting turbulence, the capacity of the entry is underestimated. In contrast, the proposed loading method shows a much better behavior. The average speeds at the link entry are comparable to those in the interior of the link (Figure 9a), causing little deceleration upon entry (Figure 9b). Flows are no longer artificially disrupted by the decelerations of entering vehicles (Figure 9b).

In addition, the impact of the loading mechanism is assessed using the hybrid simulation model MiMe in the same network. The mesoscopic (MEZZO) and microscopic (MITSIMLab) areas of the network are shown in Figure 10. MiMe was used to simulate the operations of the network first with the default MITSIMLab loading mechanism and then with the proposed method.
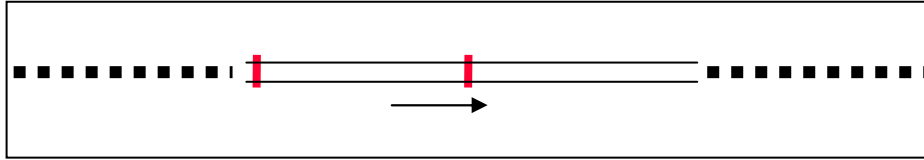
Figure 10. Test network for hybrid model MiMe

The results show that the original loading method causes disturbances that result in high accelerations (Figure 11). The behavior is similar to the behavior observed with MITSIMLab alone, although the impact seems to be greater in the hybrid model (compare Figures 9b and 11).
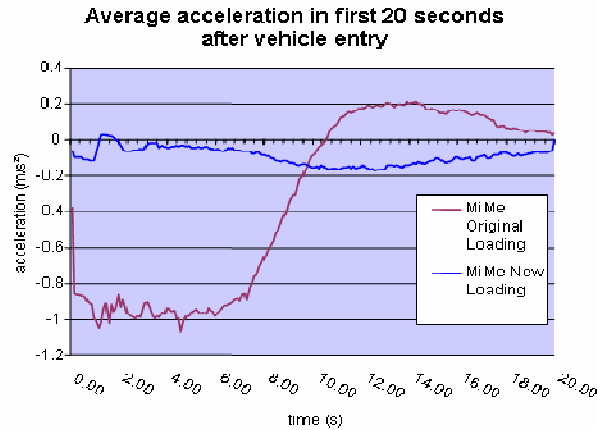

Figure 11. Entry acceleration pattern with original and proposed loading method in MiMe.

The flows, under the default loading method, are very unstable (Figure 12a). The decelerations cause heavy disruptions of the flows, due to the shockwaves that propagate backward into the mesoscopic network. The proposed loading method generates more realistic accelerations during the first 20 sec (Figure 11) and, as a result, a much better flow profile as flows are no longer artificially disrupted by the decelerations of entering vehicles (Figure 12b).
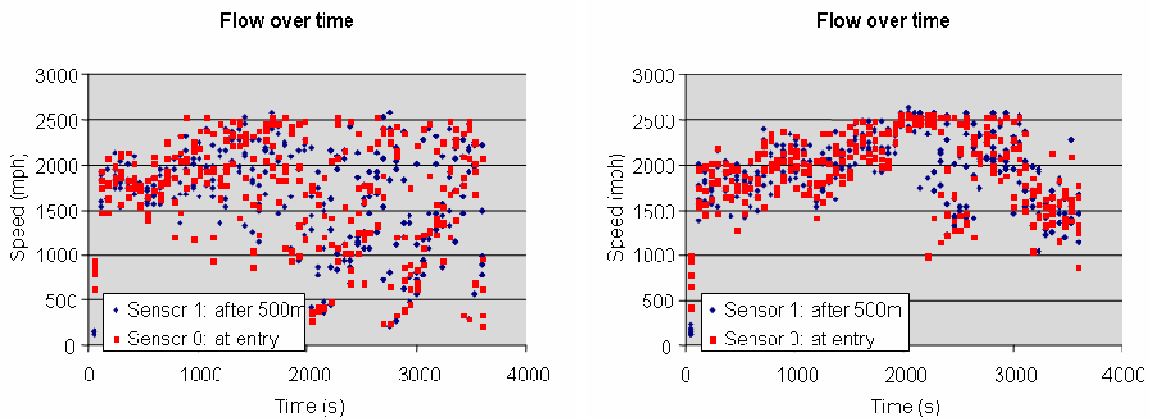
a) Original loading method.   b) Proposed loading method.

Figure 12. Flows in hybrid model MiMe

6. Conclusion

The paper discussed issues related to the integration of mesoscopic/microscopic traffic simulation models. Such hybrid models have a number of advantages over standard microscopic models, especially in large scale applications with extensive data input and calibration requirements.

Successful hybrid models require, among other things, consistent representation of traffic dynamics at the boundaries between the meso and micro networks. A critical determinant of this consistency is the loading mechanism that transfers vehicles form the meso to the micro network. The loading mechanism is important for hybrid models as well as stand alone micro models.

The paper presented an integrated framework for the development of hybrid models. In addition, the role of the vehicle loading mechanism on the validity of hybrid models (and microscopic models on their own) was also examined. A new loading method was proposed which, compared to existing approaches, resulted in a much more consistent performance. The results from a case study supported both the importance of the loading mechanism and the value of the proposed method. Inappropriate loading methods can result in excessive decelerations and accelerations, volatility and delayed vehicle entry, reduced capacity at entry points, and unnecessary turbulence and shockwave propagation.

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