Multi-level Traffic Simulation with Dynamic Simulation Level Assignment for Urban Network

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1 INTRODUCTION

Recently, the demand for traffic simulation has shifted to large-scale urban areas. Among the various levels of traffic simulation, microscopic simulations provide the most accurate and detailed results. However, their high computational cost prevents them from being applied to the large-scale urban network. In this manner, the need to find a compromise between accuracy and computational cost leads to hybrid or multi-level traffic simulation. Multi-level traffic simulation integrates different simulation levels within a single framework. Typically, micro-macro hybrid simulation is used for highways and micro-meso hybrid simulation is suitable for urban networks. Furthermore, to maintain a constant simulation performance in terms of accuracy and computational cost, the importance of dynamic properties that change the simulation levels of road segments in response to the traffic conditions over time has been emphasized. Therefore, this study proposed a dynamic multi-level traffic simulation for urban areas by combining microscopic and mesoscopic traffic simulations.

2 Dynamic Multi-level Traffic Simulation

2.1 Simulation Framework

The simulation consists of presetting, simulation unit, simulation execution, and traffic behavior models inside the simulation engine. Presetting is a set of tasks that should be performed in advance for a given target area including network editing, network parsing, and route generation corresponding to the network. A simulation unit is defined as a simulation run that maintains a constant network representation level over a specified interval. The execution of the simulation involves running one simulation unit, which is composed of environment initialization, demand generation, simulation engine, and result export.

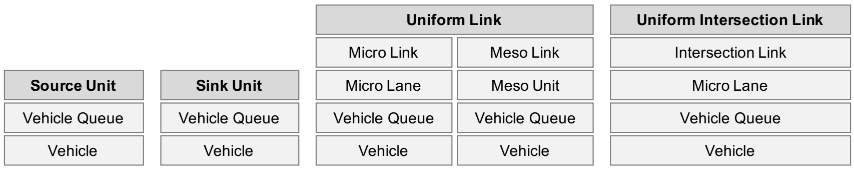


Figure 1 – *Network components*

2.2 Behavior Model

The proposed dynamic multi-level traffic simulation adopts the asymmetric repulsive-force model (ARM) as its main car-following model (Kim & Yeo, 2024). In addition, we suggest an integrated traffic flow algorithm (ITFA) by enhancing the oversaturated freeway flow algorithm (OFFA) to implement the lane-changing behavior Yeo *et al.* (2008). As a primary mesoscopic behavior model, the extended urban cell transmission model (UCTM) is used (Kim *et al.*, 2020). The UCTM is an agent-based mesoscopic traffic simulation model, extending the cell transmission model (CTM) considering urban driving behaviors.

2.3 Simulation Data Structure

The compatibility between micro-simulation and meso-simulation requires a data structure that supports consistent road representation and data exchange between both levels. To address this issue, we introduce a *uniform link*, which includes both a *micro link* and a *meso link* in parallel. This allows for seamless switching between different simulation levels within the same link. Figure 1 illustrates the network components in the proposed simulation framework.

2.4 Interface Modeling Between Microscopic and Mesoscopic Simulation

As the links dynamically change their levels over time, there are temporal and spatial interfaces between microscopic and mesoscopic simulations.

The temporal interface develops between the microscopic and mesoscopic simulations during dynamic road-level operations across simulation units. In the microscopic simulation, vehicles move individually based on car-following behavior, and their positions are updated accordingly. In contrast, in the mesoscopic simulation, vehicles within the meso unit have only relative orders within the vehicle queue and do not have exact positions. As a result, their positions are updated based on the assumption that they are uniformly distributed. Additionally, the speed of all vehicles within the meso unit is set to be equal to the average speed of the meso unit.

The spatial interface refers to the boundary of two adjacent links with different levels. While the temporal transition involves mapping traffic conditions between different simulation levels, the spatial transfer of vehicles involves bidirectional interaction between the levels.

When a vehicle moves from the mesoscopic level to the microscopic level, the inter-cell flow at the boundary between the two levels needs to be calculated based on the rules of the mesoscopic model. It requires the number of vehicles located within one meso unit length from the upstream of the micro lane and the number of vehicles in the adjacent meso unit. A calculated number of vehicles is then transferred from the following meso unit to the micro lane. To ensure a smooth integration, the entering vehicles need to continue driving in the current traffic flow. Therefore, the time headway between the most upstream vehicle in the microscopic lane and the entering vehicle is set to be equal to the time headway corresponding to the flow of the meso unit.

3 Evaluation of the Dynamic Multi-level Traffic Simulation

The efficiency of the proposed simulation was evaluated by considering both the simulation execution time and accuracy. A trade-off between the running time and accuracy is assessed, with the microscopic simulation serving as the ground truth. To assess the effective trade-off of the computational cost and simulation accuracy, we designed a 3x3 grid-shaped test network as shown in Figure 2. The region of interest encompasses the central part of the network.

We examined two demand scenarios. In the first demand scenario, a low volume of traffic demand was generated for vehicles passing through the region of interest. The second demand scenario involved demand circulating the perimeter outside the region of interest. The simulation was run for 30 minutes, and divided into six consecutive five-minute simulation units.

A total of five road-level operations were simulated, including microscopic, mesoscopic simulations, fixed operation, and dynamic operations with two different criteria for road-level evaluation. Both criteria evaluated the speed of links during the last minute of the simulation unit. The first criterion, C1, selected links with speeds below half of the free flow speed. The second criterion, C2, selected links with speeds below 0.7 times the free flow speed. The terminal links were excluded from the microscopic simulation.

The computational cost of each operation was measured as the simulation step duration, which represents the simulation running time per cycle. The simulation accuracy was evaluated using the root mean squared error (RMSE) of the number of vehicles in each link for every mesoscopic time interval, with the average results of the microscopic simulation repeated 5 times as ground truth.

Simulations were repeated 5 times for all scenarios. Figure 3 illustrates the simulation results for the low-volume demand scenario. In Figure 3 (a) and (b), the average step duration and RMSE of the simulations with error ranges are shown for different road-level operations. Multi-level simulations, including fixed and dynamic road-level operations, significantly reduced the step duration compared to the microscopic simulation. The dynamic road-level operation with criterion C2 slightly reduced the step duration compared to the fixed operation, while the dynamic operation with criterion C1 showed a particularly fast step duration. In Figure 3 (b), the dynamic operation showed different levels of accuracy depending on the criteria. Both criteria C1 and C2 showed errors similar to those of the fixed operation until the second simulation unit. After that, the RMSE of the dynamic operation with criterion C1 increased, while the dynamic operation with C2 maintained a similar RMSE to the fixed operation.

Figure 4 depicts the step duration and RMSE of the simulations for demand scenario 2. The multi-level simulations took approximately one-fourth of the step duration of the microscopic simulation with a similar trend in step duration over time. Regarding the accuracy of demand scenario 2, the fixed operation had the highest RMSE after the mesoscopic simulation, while the dynamic operation showed lower RMSE values for both criteria. This difference became more pronounced after the third simulation unit, coinciding with a longer step duration. The improved accuracy of the dynamic operation was due to the micro-simulation of the high-demand outlying roads.

In summary, the simulation results of demand scenario 1 showed the importance of the road-level evaluation criteria in the dynamic operation, emphasizing the need for an optimal road-level evaluation algorithm. In addition, the results of demand scenario 2 suggest that dynamically adjusting the road level when there is a rapid change in demand can achieve high simulation accuracy at the same computational cost.

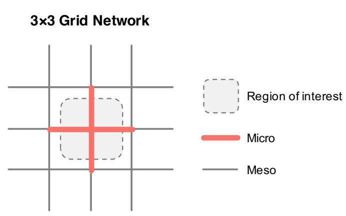
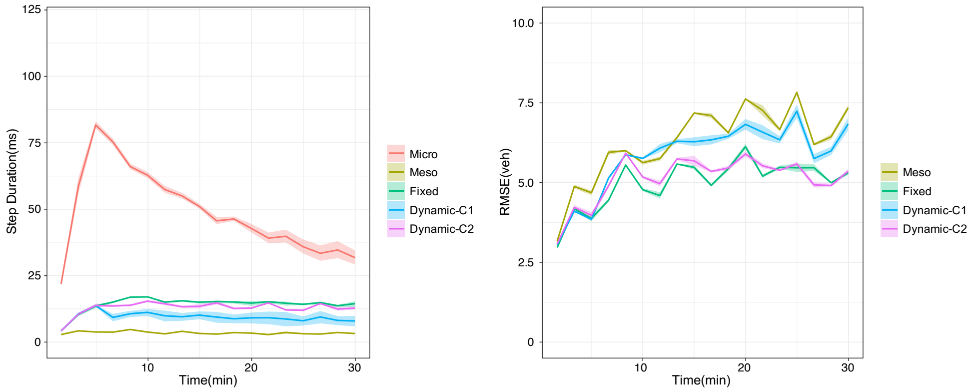
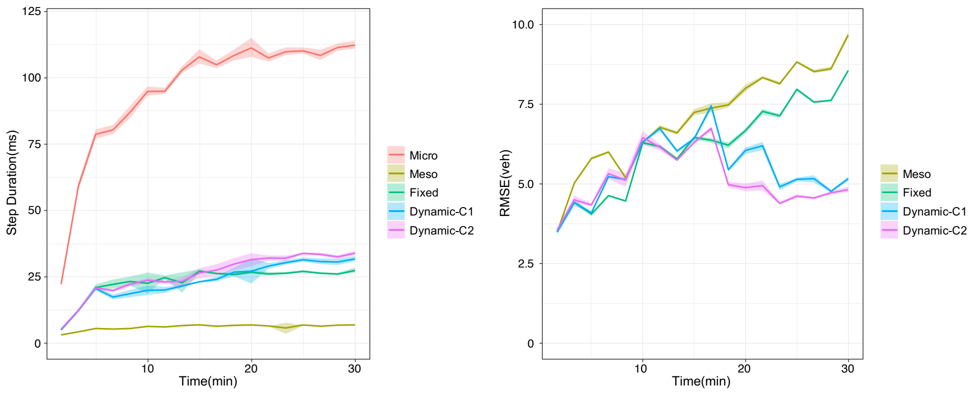


Figure 2 – *Test network*



(a) (b)

Figure 3 – *Simulation results with the low traffic volume scenario (a) step duration and (b) RMSE of the number of vehicles in the links by the road-level operations*



(a) (b)

Figure 4 – *Simulation results with the demand outside the region of interest scenario (a) step duration and (b) RMSE of the number of vehicles in the links by the road-level operations*

4 Conclusion

This study proposed a dynamic multi-level traffic simulation for urban areas by combining microscopic and mesoscopic traffic simulations. A simulation framework and data structure were proposed to ensure compatibility and consistency between different levels of simulations. Temporal and spatial interfaces were modeled and verified for proper functioning, including the preservation of vehicle information and consistency in traffic dynamics. The developed simulation was evaluated in terms of computational cost and accuracy using two demand scenarios. The dynamic multi-level simulation dramatically reduces the computational time compared to the microscopic simulation while showing higher accuracy than the mesoscopic model.

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