Investigating the impact of the network density in agent-based transport modelling: A case study for the Metro Vancouver region using MATSim

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Introduction

Agent-based modelling in transportation offers a more accurate representation of individual agents' decisions and behaviours related to traditional models. A detailed and well-defined spatial and temporal resolution in agent-based models is paramount, as capturing agent interactions and adaptive behaviours is crucial. Accordingly, an accurate representation of the network is not just important; it is a necessity. However, this increased accuracy and versatility come with a trade-off of significantly increased data and computational requirements, often at detailed disaggregated levels. A modeller needs to determine the appropriate level of detail in the network, known as network density, based on the simulation's specific objectives, required accuracy, and performance constraints. A detailed network with well-defined link types offers a high theoretical precision; however, it also substantially increases the computational load, resulting in longer run times and greater demands on processing power and memory. Conversely, simplifying the network with fewer details or generalized link types may lead to losing crucial information necessary for making informed decisions.

This research study offers valuable insights for agent-based transport demand modellers to establish the optimal network density for road traffic in terms of used link categories by comparing result accuracy and model run times. The research questions were examined using an agent-based traffic simulation model designed for Metro Vancouver using the MATSim (Multi-Agent Transport Simulation) platform.

Optimizing agent-based models (including MATSim) involves implementing several strategies such as hardware acceleration, deeper-level parallel processing, multi-threading [1], [2], employing more efficient logic and algorithms [3] , etc. The findings from this research could also be used as one methodology to reduce model runtimes without compromising accuracy and enhance the efficiency of agent-based transport models.

Methodology

The MATSim model used in this study was developed, calibrated and validated for the Matro Vancouver region, with 2023 as the base year. The agent plans were developed using the Travel Demand Modelling (TDM) platform, developed and maintained by the UBC Integrated Transport Research Lab (UiTR) at the University of British Columbia Okanagan Campus. Agent plans cover 271,145 persons, 10% of Metro Vancouver's population. The Plans use an extensive list of activity types: Home, Intermediate Home, Work, School, pick-up/drop-off, Personal, Shopping, Social, Recreation, Restaurant, and Other. The plans file contains travel legs with six modes: Auto, Auto Passenger, Walk, Bike, Transit and Sky Train. The network file was developed using the OpenStreetMap data and MATSim built-in tools. The model calibration was conducted in four ways. Mode choice and trip length calibrations were carried out to match the British Columbia Activity Time-Use Survey (BCATUS) data. Hourly traffic volume calibrations were conducted for selected locations on major roads covering the Metro Vancouver area, considering data availability.

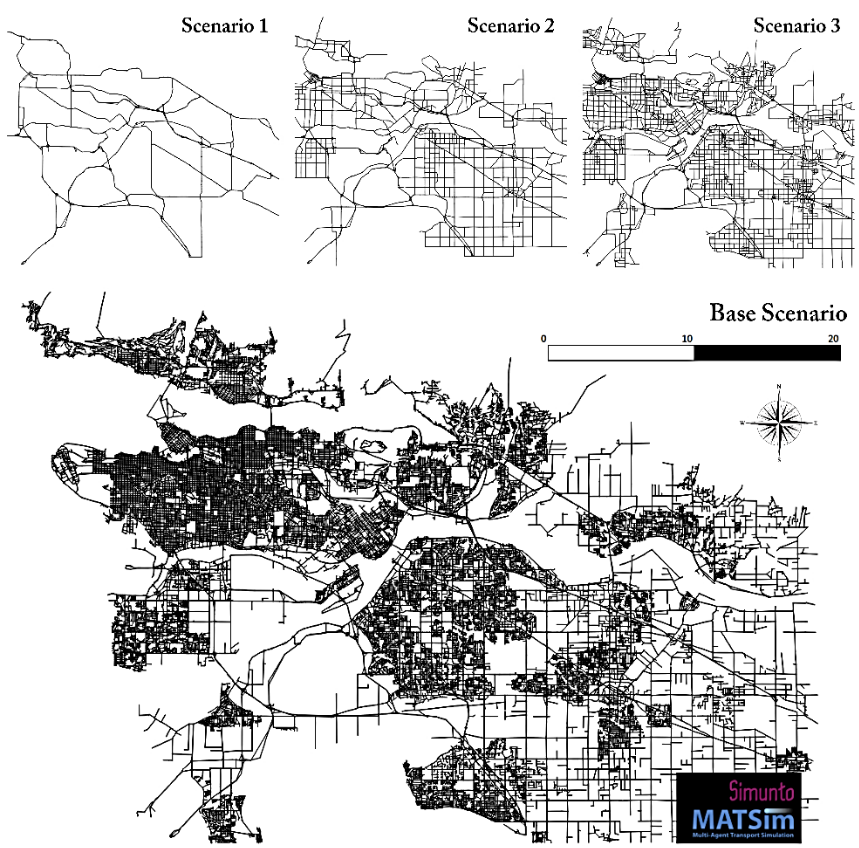
The MATSim model was run on four scenarios, considering four combinations of link types to test the effects of network density. The basis of developing the network scenarios is showcased in Table 1. Inside the MATSim network file, the network scenarios were accommodated by conditionally matching the link attribute ‘class’ against the link attribute ‘modes’, which dictates which modes are allowed to travel. Accordingly, the network.xml file developed through MATSim’s OsmNetworkReader was post-processed to introduce the necessary changes to build the four scenarios. Developed Networks are shown in Figure 1.

The MATSim model for each network scenario was run for 200 iterations with the developed scenario-dependent parameters. The rest of the input files and model run environments were the same for all the scenarios. Agents were forcibly forbidden from changing plans to negate the effects of mode shift between scenarios. Network assignment was conducted only in ‘auto’ mode using the Queue Simulation (QSim) of MATSim.

Table 1. Network Link Types Used in Scenarios

Link Type	Canadian Classification	Number of Links		Scenario 1	Scenario 2	Scenario 3	Scenario 4 (Base)
		Number	%				
motorway	Freeway/Expressway	1,012	0.70%	✓	✓	✓	✓
motorway_link	Freeway Ramp/Connector	1,166	0.80%	✓	✓	✓	✓
primary	Major Arterial	4,209	3.00%	✓	✓	✓	✓
primary_link	Major Arterial Connector	609	0.40%	✓	✓	✓	✓
trunk	Major Arterial	337	0.20%	✓	✓	✓	✓
trunk_link	Major Arterial Connector	1,396	1.00%	✓	✓	✓	✓
secondary	Major Collector	18,558	13.20%	×	✓	✓	✓
secondary_link	Major Collector Connector	646	0.50%	×	✓	✓	✓
tertiary	Minor Collector	22,092	15.70%	×	×	✓	✓
tertiary_link	Minor Collector Connector	145	0.10%	×	×	✓	✓
residential	Local Road	87,342	62.20%	×	×	×	✓
living_street	Local Road	2,969	2.10%	×	×	×	✓
Note—OSM link categories identified as bridleway, busway, construction, corridor, cycleway, demolished, disused, footway, path, pedestrian, planned, Primary, proposed, raceway, service, services, steps, or track were not considered in the base scenario as the OsmNetworkReader removes these link types.							

Figure 1. Geographical Representation of Scenario Networks

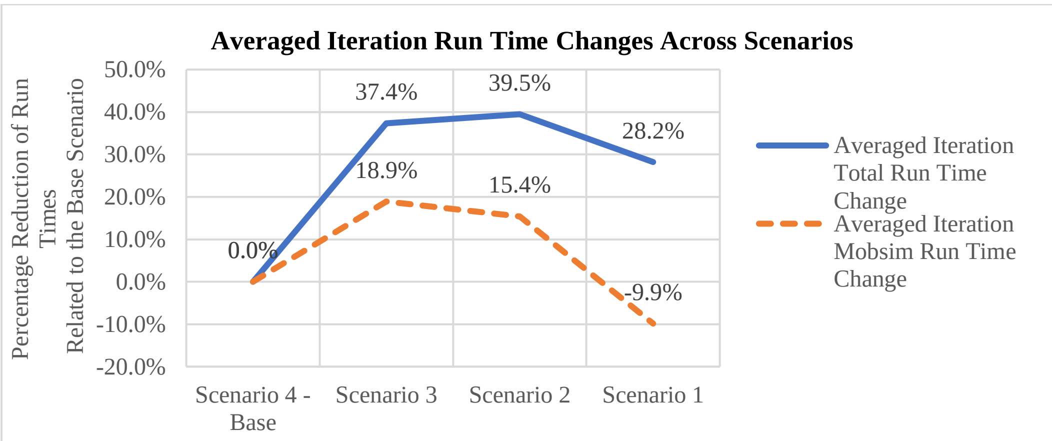


Results

The introduced scenario-based changes primarily impact the 'auto' mode. Any impact on the other modes is insignificant as they were quantitatively more minor and determined within the model's noise. Hence, the analysis and results section primarily discusses the impact of the overall model and the 'auto' mode.

When compared across the model run times, an initial trend of reduced run times on both total and mobility simulation (Mobsim) could be observed with the decreasing network density. With scenarios 1 and 2, a reverse pattern could be observed. Interestingly, scenario 1 reported that the averaged Mobsim run time is more than the base scenario's Mobsim run time. The best hypothesis to explain the behaviour is that the lesser network density increases the traffic congestion, leading to significant run time increments for the replanning module, which requires further investigation. The behaviour is presented in Figure 2.

Figure 2. Averaged Iteration Run Time Changes Across Scenarios



With the reduced network density, Mobsim's share of the total iteration run time has reduced, and the reported values from scenario 1 to scenario 4 are 88%, 65%, 61%, and 47%, respectively. A significant change in scoring stats was not observed across the scenarios.

Table 2 demonstrates significant variations in key performance indicators across different scenarios compared to the base scenario. Scenario 1 exhibits the most substantial increases, with passenger hours increasing by 443.06% and passenger kilometres rising by 46.11%, indicating a significant increase in the time passengers spend in transit and the distance travelled. This is caused by significantly increased congestion due to limited mobility with the less dense road network. Scenario 2 also shows notable growth, with a 42.03% rise in passenger hours and a 7.77% increase in passenger kilometres. Scenario 3 presents a moderate increase in passenger hours by 12.85% and a marginal rise in passenger kilometres by 0.50%. Scenario 4 serves as the baseline with no change in either metric.

Table 2. Comparison of Key Performance Indicators

Scenario	Passenger Hours		Passenger Kms	
	Value	Percentage Change	Value	Percentage Change
Scenario 1	419,349	443.06%	1,821,226	46.11%
Scenario 2	109,677	42.03%	1,343,320	7.77%
Scenario 3	87,144	12.85%	1,252,779	0.50%
Scenario 4 - Base	77,220	0.00%	1,246,487	0.00%

Conclusion

Using four network scenarios, the study investigated how network density affects agent-based model performance and accuracy. Scenarios were developed with increasing network densities from one to the other. Scenario 1 included only the major road types (motorways, primary roads, trunk roads, and connecting links). In contrast, scenario 4 represented a typical road network where no road categories are excluded from the network development. It matches most of the networks developed for MATSim simulations by modellers, as MATSim documentation recommends.

The study reveals that a reduction in network density generally leads to decreased run times for total and mobility simulation (Mobsim) iterations. A clear pattern could be identified: with decreasing network density, the reduction in model runtimes gradually plateaus and then increases. The pivotal point can be associated with scenario 03, where all typical road types used by auto users are used for the analysis, apart from the residential and living streets. The computed 37% reduction of the iteration run time and the 18.9% reduction in Mobsim run time for the scenario match some of the hardware acceleration and logic improvements introduced to MATSim. [2], [3], [4], [5]. Regarding accuracy, scenario 03 fares well against the base scenario, which is calibrated with the traffic data. The simulation results suggest a mere 0.5% increment in passenger kilometres and a 12.85% increment in passenger hours related to the base scenario. The latter value is slightly above the 10% acceptable deviation in the transport modelling practice. The 12.85% value can vary based on the calibration accuracy obtained with the base scenario. One may argue that given some of the broader assumptions still used in agent-based modelling, slight deviations beyond the acceptable margins might not be significant.

Considering the presented facts, scenario 03 is suggested as a potential alternative for the current agent-agent-based simulation's network developing practice using OSM data.

The model tested was developed to calculate road users' emissions and test the effects of emission policies. The effects of the approach might not yield the same results when the primary purpose of the mode development is localized congestion analysis, infrastructure developments, or much finer applications such as traffic signal design [6]. However, the approach is not expected to create freight or land use integration mismatches. [7], [8]. Further, agents can respond to changes in the road network, but in this analysis, agents were limited to one plan, which is not realistic. This is a limitation of the study. The analysis focused solely on the road network for vehicular modes. Still, minor road types should not be overlooked when considering micro-mobility and modelling complex mixed-mode tours to ensure accessibility. Public transit routes typically avoid residential or living streets, so if they are used, it could pose integration problems for public transit if oversimplification is employed.

Acknowledgement

The authors thank the NSERC - Alliance Missions Grant for the financial support.

References

[1] S. Moukir, N. Emad, and S. Baudelocq, "From MATSim to MultiMATSim: Rethinking Traffic Modeling Using the 'Unite and Conquer' Approach," *Proceedings - 2023 IEEE International Conference on High Performance Computing and Communications, Data Science and Systems, Smart City and Dependability in Sensor, Cloud and Big Data Systems and Application, HPCC/DSS/SmartCity/DependSys 2023*, pp. 288–295, 2023, doi: 10.1109/HPCC-DSS-SMARTCITY-DEPENDSYS60770.2023.00047.

[2] A. Saprykin, N. Chokani, and R. S. Abhari, "Large-scale multi-agent mobility simulations on a GPU: towards high performance and scalability," *Procedia Comput Sci*, vol. 151, pp. 733–738, Jan. 2019, doi: 10.1016/J.PROCS.2019.04.098.

[3] D. Graur *et al.*, "Hermes: Enabling efficient large-scale simulation in MATSim," *Procedia Comput Sci*, vol. 184, pp. 635–641, Jan. 2021, doi: 10.1016/J.PROCS.2021.03.079.

[4] J. Casas, J. Perarnau, and A. Torday, "The need to combine different traffic modelling levels for effectively tackling large-scale projects adding a hybrid meso/micro approach," *Procedia Soc Behav Sci*, vol. 20, pp. 251–262, Jan. 2011, doi: 10.1016/J.SBSPRO.2011.08.031.

[5] R. A. Waraich, D. Charypar, M. Balmer, and K. W. Axhausen, "Performance improvements for large-scale traffic simulation in MATSim," *Computational Approaches for Urban Environments*, pp. 211–233, Jan. 2015, doi: 10.1007/978-3-319-11469-9_9.

[6] T. Ziemke and S. Braun, "Automated generation of traffic signals and lanes for MATSim based on OpenStreetMap," *Procedia Comput Sci*, vol. 184, pp. 745–752, Jan. 2021, doi: 10.1016/J.PROCS.2021.03.093.

[7] M. Ben-Akiva and G. de Jong, "The Aggregate-Disaggregate-Aggregate (ADA) Freight Model System," *Freight Transport Modelling*, pp. 69–90, May 2013, doi: 10.1108/9781781902868-004.

[8] D. Ziemke, K. Nagel, and R. Moeckel, "Towards an Agent-based, integrated land-use transport modeling system," *Procedia Comput Sci*, vol. 83, pp. 958–963, 2016, doi: 10.1016/j.procs.2016.04.192.