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Spatiotemporal Implications of Population Downscaling: A MATSim Study of Sioux Falls Morning Peak Traffic

Golan Ben-Dor [a*], Eran Ben-Elia[b], Itzhak Benenson[a]

[a]*Department of Geography and Human Environment, Faculty of Exact Science, Tel-Aviv University, Israel*
[b]*Department of Geography and Environmental Development, Ben-Gurion University of the Negev, Israel*

Abstract

Computer hardware is steadily advancing; however, simulating real urban transportation systems that serve millions of individual travelers is still a difficult task. The Multi-Agent Transportation Simulation (MATSim) is the only agent-based traffic model that includes intrinsic downscaling - procedures of changing network parameters in order to simulate the dynamics of the system as a whole while activating only a fraction k of travelers. In this paper, we present the MATSim's downscaling procedure and compare the dynamics of car traffic in the downscaled and full-scaled scenarios of the Sioux Falls test case. We compare aggregate and disaggregate statistics that represent Sioux Falls daily traffic, focusing on the morning peak. We conclude that downscaling up to $k = 0.25$ preserves all major statistics of urban traffic, within the interval of k between [0.1, 0.25]. Some of the statistics replicate well the statistics of the full-scaled runs, while downscaling below $k = 0.1$ can easily result in substantial deviations from the dynamics of the full-scale model.

Keywords: Agent-Based simulation; MATSim; Car traffic; Downscaling; Morning Peak

* Corresponding author. Tel.: +972-522-937463
E-mail address: golanben@mail.tau.ac.il

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1. Introduction

Multi-Agent Systems (MAS) aim at representing the heterogeneity of agents' behavior in heterogeneous urban space [1]. However, to understand the collective dynamics of complex urban systems, the agent population should be sufficiently large, especially when spatially-explicit transportation infrastructures are considered. The larger is an urban area; the higher is the demand for better model performance. This positive relation is fundamentally super-linear. As every agent, be it a traveler or a vehicle, interacting, when moving in space with many other agents, metropolitan areas populated by millions of travelers become a significant challenge to MAS modeling.

Two practical ways to simulate metropolitan traffic at a resolution of individual agents are either to consider a part of the metropolitan area or a part of the entire metropolitan population. The first approach imposes an unnatural limitation on the length of the travelers' trips and, thus, the second one is preferable. Simulating urban transportation dynamics with a fraction of travelers is called "downscaling" [3], and it demands to adjust the model parameters to guarantee that the dynamics of the downscaled system will replicate the dynamics of the full-scaled one [2]. Out of a dozen spatially explicit multi-agent traffic simulators, only one – MATSim, possesses an intrinsic downscaling procedure. Downscaling in MATSim is widely exploited [2, 4-8] and demands simple adjustments of the network link parameters concerning the selected fraction k of the traveler population. Despite vital interest [9-12] and important initial experiments [12], we still lack systematic studies of downscaling implications. In this paper, we investigate downscaling effects on morning traffic of the city of Sioux Falls, South Dakota [13], a well-documented transportation planning testbed, including MATSim.

2. Downscaling in MATSim

MATSim considers traffic flows at the mesoscale level. It does not explicitly simulate car following and, instead, employs a First-In-First-Out (FIFO) approach for simulating link traversal by vehicles. A vehicle that enters a link joins the queue and remains there until reaching its head. The traversal time is dependent on the current traffic conditions on the link [3], and the queue of vehicles within the link of limited capacity generates traffic congestion there. Agents in MATSim follow their activity plans and adapt to evolving traffic conditions by varying route, mode, or departure time. The daily score serves as an estimate of the utility of an agent's plan. Changes in agents' behavior entail traffic changes, and the daily MATSim loop is reiterated until a user equilibrium (UE) is established where no agent can improve its daily scores.

2.1. MATSim downscaling rules

In a MATSim downscaled simulation, a fraction k of the travelers' population is randomly chosen as representing the entire population, and the network capacity parameters are modified for the chosen fraction k. For example, k = 0.1 demands selection of 10% of travelers' population. We will interchangeably call this run "0.1-downscaled" or "10%-downscaled" model. In these terms, the full-scale model (k = 1) is 100%-downscaled. The modified parameters include the *flow capacity* - maximal number of vehicles per second that can leave a link and *storage capacity* - maximal number of vehicles that can be physically allocated on a link. In a full-scale version of the model, these capacities are calculated as

$$flow\_capacity\_full = \frac{capacity\_value\_of\_link}{capacity\_period\_of\_network} \quad (1)$$

$$storage\_capacity\_full = \frac{length\_of\_road\_link * number\_of\_lanes}{effective\_cell\_size} \quad (2)$$

When downscaling, the flow capacity is modified linearly, while the storage capacity non-linearly:

$$flow\_capacity\_downscaled = flow\_capacity\_full * k \quad (3)$$

$$storage\_capacity\_downscaled = full\_storage\_capacity * k^{0.75} \quad (4)$$

For example, in a 10%-downscaled model $flow\_capacity\_full$ is multiplied by k = 0.1, and $storage\_capacity\_full$ in is multiplied by $k^{0.75} = (0.1)^{0.75} = 0.1778$. The 0.75 exponent in equation *(2)* was proposed by [15] to avoid network breakdowns related to excessively congested links [16] and justified by [12].

3. Methodology

3.1. The Sioux Falls MATSim Scenario

The Sioux Falls (SF) road network is a well-documented test case for transportation planning, adapted for MATSim by [13]. It consists of 334 links and 282 nodes. The road links include two types: Urban Road – two-lane links with a flow capacity of 800-1,000 cars per lane per hour, and Highway - three-lane links with a flow capacity of 1,700-1,900 cars per lane per hour [13]. The SF 2014 traveler population has 84,110 agents, who are insufficient to generate congestion even in the peak hours. For this reason, we duplicated the SF population and considered 168,220 agents as the full scenario (k = 1). The modal split in SF is 78% car use and 22% transit [13], here we consider only car traffic.

We investigate downscaling scenarios by varying k between 1 and 0.01 and apply parameters of the scoring functions, proposed by [13]. All simulations were run with 3000 iterations, including plan innovations - re-routing and change of departure time - applied for 1% of randomly selected agents up to iteration 2700. Agents contain memory slots for five plans, and when a new plan is adopted, the worst one is removed. For the remaining 300 iterations, innovations are switched off, but agents' adaptation continues until the end of the run. In what follows, we investigate the effects of downscaling based on traffic dynamics in SF during the morning peak (06:30-11:00).

3.2. Descriptive statistics of model dynamics

To study the effects of downscaling we investigate several statistics at different levels of spatiotemporal aggregation: (1) agents' average daily executed scores, (2) trip duration, (3) number of car departures, (4) traffic volume and (5) the volume to capacity ratio (V/C). The number of departures and traffic volumes are expected to depend linearly on k and we multiply these statistics in the downscaled runs by $1/k$ in order to compare them to the full-scale model statistics.

We denote statistic c obtained in k-downscaled run i, as c_i^k, and its average, standard deviation and coefficient of variation as m_c^k, s_c^k and CV_c^k, respectively. The statistics of the full-scale runs provide the basis for comparison. We repeated these runs 10 times (following [11]) and, given statistic c, denote its average over these runs as m_c^1, standard deviation (STD) as s_c^1 and coefficient of variation as CV_c^1. The comparison between the downscaled and full-scaled runs is based on the relative difference between the downscaled run statistic (c_i^k) and its average value in the full run m_c^1. The relative bias b_i^k of output statistic c in the k-downscaled scenario is thus:

$$b_i^k = \frac{c_i^k - m_c^1}{m_c^1} \qquad (5)$$

We present the average relative bias m_b^k, and the STD of the bias s_b^k, the latter having a meaning similar to the CV of the absolute bias. Each statistic is estimated based on 10 repetitions of each scenario with a different random seed, and we present m_b^k and s_b^k. We consider the dependence of statistic c on k in the k = 1 to k = 0.01 direction. We consider statistic c as robust to k-downscaling if its average relative bias m_b^k is close to zero and the STD s_b^k of the bias is close to $CV_c^1/\sqrt{k}$. Ideally, the relative bias can be zero if the bias is zero in every downscaled run. In this case, the STD will be lower than $CV_c^1/\sqrt{k}$ and one downscaled run can be sufficient for estimating the statistic. If the bias is close to zero, but the STD is $CV_c^1/\sqrt{k}$ or higher, there may be a need, depending on the demanded precision, to repeat the downscaled scenario several times. If the bias of the k-downscaled runs is non-zero, it would be the researcher's decision whether to accept the bias or re-run MATSim simulations with a higher k fraction.

4. Downscaled statistics of the SF morning peak scenario

SF Traffic dynamics in 10 repetitions of the full-scale scenario are very close to each other and, for all investigated statistic, CV_c^1 never exceeded 5%. However, downscaling affect these statistics differently.

4.1. Average network statistics

Average daily executed scores have a small but systematic positive bias for the values of $k \leq 0.5$. This bias remains below 1% up to $k \sim 0.05$, and the bias STD for $k \leq 0.5$ is also below 1%. We thus consider scores as practically unaffected by downscaling. The number of car departures is the most robust statistic that remains invariant to downscaling up to $k = 0.05$ (Fig. 1b). The relative bias of this statistic is close to zero, and the bias STD grows monotonously and proportionally to $CV_c^1/\sqrt{k}$ where $CV_c^1 = 0.06\%$. Even 5%-downscaling is considered safe. This robustness is quite expected since the shift in departure time is not a preferred innovation for the relatively light morning peak congestion of SF. The relative bias of the hourly traffic volume behaves similarly to that of the number of departures up to $k = 0.15$, whereas its STD varies much more and reaches ~11.5%, which is essentially higher than $CV_c^1/\sqrt{k}$ ($CV_c^1 = 4.8\%$), already for $k = 0.4$ (Fig. 1c). For $k < 0.15$, the relative bias of traffic volume is steadily positive, while still insignificantly different from zero when considered for each k separately. For all runs with $k < 0.15$, the combined difference is positive and significantly different from zero at $p < 0.05$. We thus consider 15% downscaling as safe.

The hourly average trip duration has the least robustness out of the four investigated statistics. Its relative bias fluctuates starting from $k = 0.5$, and the bias STD is disproportionally high for $k = 0.5$ as well as for the lower k, too (Fig. 1d). According to Fig. 1d, for $k < 0.5$, the relative bias of the average trip duration is mostly negative, and its dependence on k is irregular. The first (negative) average bias of 10% is observed for $k = 0.25$. Thus we cannot recommend downscaling below 30% if this statistic is regarded as necessary for the study. Low robustness of the downscaled hourly average trip duration can be related to the dependency of the agents' route choice on the instantaneous traffic state and possible switch between the routes of different lengths or variations in the congestion rate along the chosen route. We delay this investigation for future study.

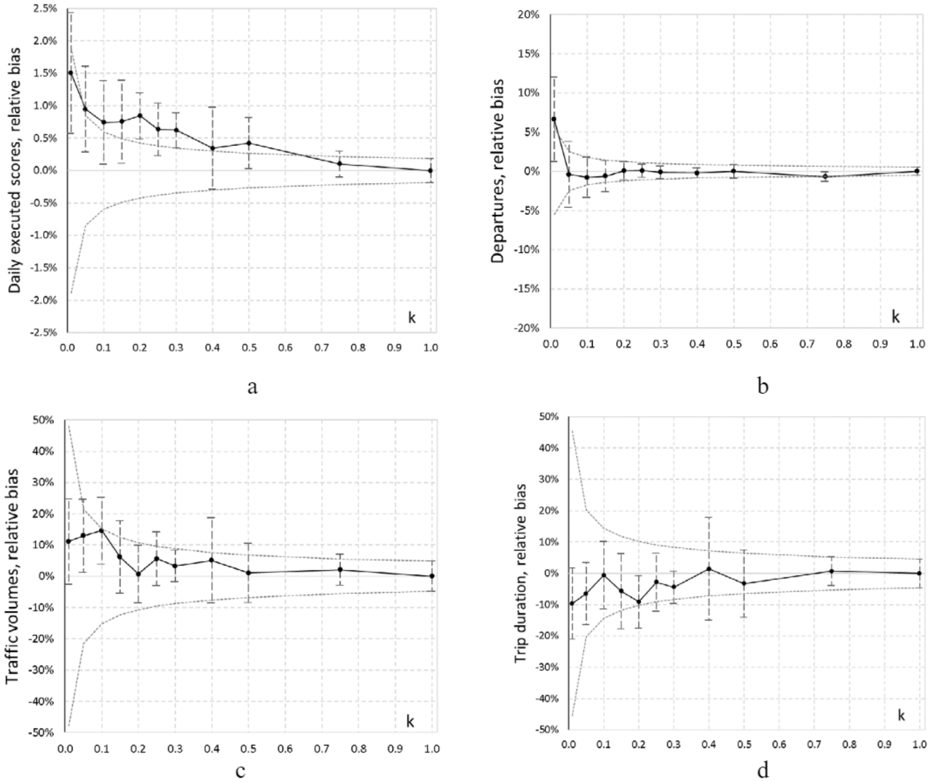


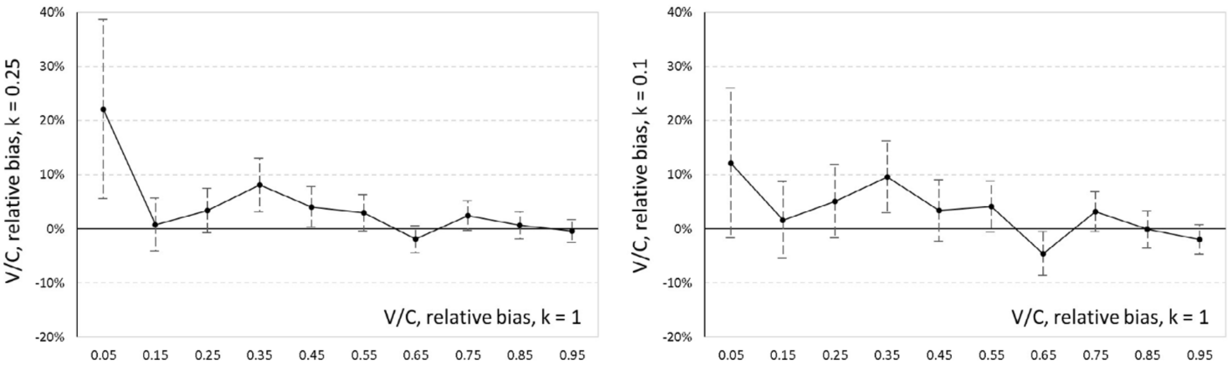
Fig. 1. The average relative bias and its STD during the morning peak for (a) average agents' executed scores; (b) number of departures; (c) traffic volumes; (d) average trip duration. Dashed curves denote $\pm CV_c^1/\sqrt{k}$

4.2. Spatially explicit statistic

Downscaling effects on congestion demands a spatial view of the V/C ratio. The maps of V/C averaged over the hours of the morning peak, and over 10 simulation runs for k = 1 (full-scale run), and two sets of downscaled scenarios for k = 0.25 and k = 0.1 is presented in Fig. 2. Visually, all three maps appear quite similar. To check the match between congested/uncongested links in the full-scaled and downscaled scenarios, we estimated the average relative bias and bias STD in the downscaled scenarios, combining links by groups of V/C as obtained in the full-scaled scenario (Fig. 3). As can be seen in Fig. 3, the relative bias for V/C ≥ 0.7 (intermediate and poor level-of service -LOS) is very low, and the bias STD for this interval of V/C is low too. For V/C < 0.7 (good LOS), the bias is mostly positive but varies irregularly, and, as expected, the traffic on the less used links is less adequately replicated in the downscaled versions.

a b c

Fig. 2. Average hourly V/C maps during the morning peak for (a) k = 1; (b) k = 0.25; (c) k = 0.1.



a b

Fig. 3. The average relative bias and bias STD for hourly V/C during the morning peak in two downscaled scenarios by the 0.1-width intervals of V/C in full-scale scenario, k = 0.25 (a), and k = 0.1 (b).

5. Discussion

The analysis of downscaling effects in MATSim on the statistics of Sioux Falls' morning peak traffic demonstrates that some statistics are quite robust to downscaling. In contrast, others should be treated with more care. Among the aggregate statistics, the number of departures is the most robust statistic, with up to 5% downscaling can be applied safely. V/C makes more sense when considered spatially, and 25%- and 10%-downscaling tests demonstrate its robustness to downscaling for the most links where V/C during the morning peak is below 0.7. As can be expected, the lower the average V/C of a link is, the less certain is the flow and, thus, the higher is the bias' STD.

The evident limitation of our study is its focus on car-only traffic. The reason for this is the use of the downscaling transformations *(3) – (4)* that are based on a car-focused view of urban traffic. With mixed traffic, especially when cars and public transit share the same road space, these transformations are insufficient since the number of public transit vehicles cannot be reduced proportionally to the reduction in the travelers' population. Less public transit vehicles will result in longer waiting times associated with downscaling itself and not by the traffic and are thus detrimental to the MATSim adaptation algorithm [17]. It is worth noting that our study is performed for the simple Sioux Falls network, and we cannot guarantee these results can be repeated in other test cases.

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References

[1] Benenson, Itzhak, and Torrens M. Paul. (2004) "Geosimulation: object-based modeling of urban phenomena." Wiley, 2004.

[2] Bischoff, Joschka, and Maciejewski, Michal. (2016) "Autonomous taxicabs in Berlin–a spatiotemporal analysis of service performance." *Transportation Research Procedia* **19** (176-186).

[3] Horni,Andreas., Nagel Kai, KW Axhausen, 2016. *The multi-agent transport simulation MATSim,* London: Ubiquity Press.

[4] Ciari, Francesco, Balmer, Michael, and Axhausen W. Kay. (2008) "A new mode choice model for a multi-agent transport simulation." .

[5] Bekhor, Shlomo, Dobler, Christoph, and Axhausen W. Kay. (2011) "Integration of activity-based and agent-based models: case of Tel Aviv, Israel." *Transportation Research Record* (38-47).

[6] Bischoff, Joschka, and Maciejewski, Michal. (2016) "Simulation of city-wide replacement of private cars with autonomous taxis in Berlin." *Procedia computer science* **83** (237-244).

[7] Tchervenkov, Christopher, Molloy, Joseph, and Axhausen W. Kay. (2018) "Estimating externalities from GPS traces using MATSim." .

[8] Waraich, Rashid, Axhausen, Kay. (2012) "Agent-based parking choice model." *Transportation Research Record:* (39-46).

[9] Hemdan, Seham, Wahaballa M. Amr, and Kurauchi, Fumitaka. (2018) "Travel Time Variability and Macroscopic Fundamental Diagram Relationships in Multimodal Networks." *International Journal of Intelligent Transportation Systems Research* (1-11).

[10] Horni, Andreas, Charypar, David, and Axhausen W. Kay. (2011) "Variability in transport microsimulations investigated for MATSim: preliminary results." *[Arbeitsberichte Verkehrs-und Raumplanung]* **676**.

[11] Zhuge, Chengxiang, Shao, Chunfu, Wang, Shuling, and Hu, Ying. (2017) "Sensitivity analysis of integrated activity-based model: using MATSim as an example." *Transportation Letters* (1-11).

[12] Llorca, Carlos, and Moeckel, Rolf. (2019) "Effects of scaling down the population for agent-based traffic simulations." *Procedia Computer Science* **151** (782-787).

[13] Chakirov, Artem, and Fourie, Peter. (2014) "Enriched Sioux falls scenario with dynamic and disaggregate demand." *Arbeitsberichte Verkehrs-und Raumplanung* **978**.

[14] Paulsen, Mads, Rasmussen, Thomas Kjær, Nielsen, and Otto Anker. (2018) "Output variability caused by random seeds in a multi-agent transport simulation model." *Procedia computer science* **130** (850-857).

[15] Thomas W. Nicolai. (2012) "Using MATSim as a travel model plug-in to UrbanSim". VSP Working Paper, 12-29, TU Berlin, Transport Systems Planning and Transport Telematics.

[16] Rieser, Marcel, and Nagel, Kai. (2008) "Network breakdown "at the edge of chaos" in multi-agent traffic simulations." *The European Physical Journal B* **63** (321-327).

[17] Ben-Dor, Golan., Dmitrieva, Bella, Maciejewski, Michal, Bischoff, Joschka, Ben-Elia, Eran, and Benenson, Itzhak. "MATSim simulations in the Tel Aviv Metropolitan Area: Direct competition between public transport and cars on the same roadway." Retrieved on 16.12.19 from: http://transp-or.epfl.ch/heart/2017/abstracts/hEART2017_paper_110.pdf/.