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Modeling the Effect of Congestion Charge and Parking Pricing on Urban Traffic: Example of Jerusalem

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Abstract. Transportation Network Companies (TNC), like Uber, Lyft, and VIA, started their activities a decade ago with a far-reaching hope that Mobility-On-Demand (MOD) transportation services would decelerate or even stop the ever-growing congestion. However, it didn't happen; the negative incentives, like congestion charges and higher parking prices, seem to be the only policy tools for influencing congestion and associated negative externalities like pollution and noise. The question is whether we can establish socially acceptable congestion charges and parking prices that will effectively reduce the arrivals and traffic in highly congested areas and become the background for the future MOD arrangement? We employ the MATSim agent-based simulation model (Horni et al., 2016) of multi-modal traffic in Jerusalem Metropolitan Area (JMA) to address this problem. We investigate whether the combination of congestion and parking prices can force drivers to use Public Transport (PT), thus reducing arrivals with the private cars into the center of the city. The model study demonstrates that a reasonable charge of 7-12€ for entering the city center could decrease arrivals by 25%. From the transport policy point of view, the effects of congestion charges and parking prices are different – the increase in the congestion charges decreases arrivals. In contrast, the increase in parking prices decreases the dwell time. We discuss the policy consequences of employing each of the two mechanisms.

Keywords. Agent-Based Simulation; MATSim; Congestion pricing; SAV; parking pricing

1 Introduction

The transportation system is the heart of every city, and the match between demand for travel and the supply of transportation services defines the health of this system. Current emerging Transportation Network Companies (TNC), like Uber, Lyft, and VIA, brought a broad belief that they would get a far-reaching decline in congestion (Fagnant & Kockelman, 2014). However, recent studies question this view (Schaller, 2021). A possible near-term solution to reducing traffic congestion by enforcing the transition from private cars to PT services is a Pigouvian tax (Pigou, 1920) - which exists in current transportation systems in the form of congestion and parking prices and may correct significant negative externalities like congestion, air pollution, and noise (Baghestani et al., 2020; Gu et al., 2018; Small & Yan, 2001; van den Berg & Verhoef, 2011).

The introduction of congestion pricing was considered in many cities, yet only five succeeded in doing that to date: Singapore, London, Stockholm, Milan, and Gothenburg. The rest failed due to solid public opposition (Gu et al., 2018). The implemented schemes are all cordon-type – the car is charged when passing the charging points at one of the entrances to the congested area AbuLibdeh (2017).

To understand the impact of the congestion charges and parking pricing on urban traffic, we have to foresee travelers' reactions to them. An Agent-Based Modelling (ABM) framework can provide a testbed to assess these effects (Kaddoura et al., 2020), and we apply Multi-Agent Transport Simulation (MATSim) for this purpose. Several researchers applied Agent-Based models for studying the effects of congestion (Zheng et al., 2012; Agarwal & Kickhöfer, 2015; He et al., 2021, Kaddoura et al., 2020), but we are not aware of investigating the effects of congestion charges and parking prices simultaneously. We apply our model in the highly congested city of Jerusalem.

MATSim is a popular open-source transportation simulation framework that focuses on travelers' adaptation to everyday traffic conditions via travel mode, route, and time (Horni et al., 2016). MATSim is suited for the task as it affects urban traffic at a resolution of individual travel within the explicit GIS-based urban environment. MATSim agents adapt to the existing traffic conditions through learning and self-correction (Horni et al., 2016). MATSim's advantage is in its ability to simulate traffic and transportation in realistic urban settings and analyze a vast urban system based on the simulation of a fraction of its population (Ben-Dor et al., 2020). This study applies MATSim to investigate the effects of congestion charges and parking prices in the Jerusalem Metropolitan Area (JMA).

2. Establishing the Jerusalem MATSim model

The Jerusalem MATSim model **(**JMATSim**)** is calibrated and validated based on 2017-2020 data owned by the Jerusalem Transportation Master Plan Team and supplied for our study**.** The calibration process is done in several steps: Traffic Analysis Zone **(**TAZ)-based residential data is distributed between residential buildings in proportion to the building's floor area. The data on buildings and facilities is extracted from the Israeli Mapping Center database and its layers of Buildings (Figure 1) that contains important building attributes – use and height.

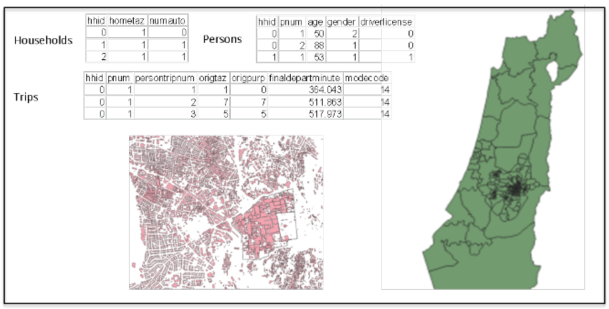


Figure 1. JMA TAZ areas (right); trip tables; and buildings

Buildings represent the origin and destination of the internal travelers. The origin of the external travels that starts the trip beyond the JMA area is represented by the centroid of the traveler's residential TAZ. The destination of the external traveler is a building with the JMA.

TAZ-based travelers' activities are assigned to the MATSim agents and spatially related to the facilities of interest represented in Jerusalem municipal GIS, like schools, offices, and shopping centers. All disaggregated data are translated into the XML format. JMA traffic is simulated with ~450k agents representing 30% of the whole metropolitan population. Agents' activities are performed at 106,173 facilities of the following types: home, work, leisure, school, and other, established based on the MAPI BANTAL land-use layer. External agents have two specific activities - trips to Jerusalem and trips from Jerusalem). Figure 2 present the view of the JMA area with the agent performing their activities.

JMATSim was calibrated against ~1,500 traffic counts according to the CADYTS procedure (Flötteröd et al., 2012), see Figure 3.

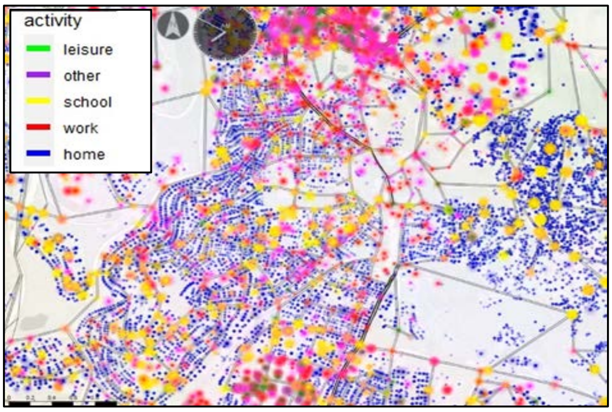


Figure 2. Agents' activities in Jerusalem at 08:00.

As can be seen in Figure 3, the fit between the reality and calibrated JMA output is very high, with R^2 = 0.826.

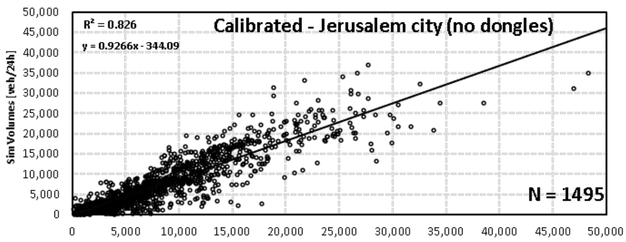


Figure 3. The fit between real and model road counts

Overall, calibrated JMATSim adequately reproduces the JMA modal split (Table 1), excluding 8% of car trips as a passenger that cannot be calibrated.

Table 1. *The match between the modal split in the travel behavior survey and JMATSim*

Mode	PT	Car	Walk	Bike
JMA survey	21.28%	32.40%	37.71%	0.60%
JMATSim	21.99%	33.09%	35.83%	1.09%

3. Congestion/parking prices as a tool for reducing congestion

Here and below, we consider model results for the JMA as a whole and several of its parts: (1) the city of Jerusalem (~10 km2) and (2) the Highly demanded area that consists of the Jerusalem's center and six areas close to it, of a total area ~3 km2 (red areas in Figure 4). These areas have been chosen for investigating the effects of congestion and parking prices. We compare scenarios with the congestion price paid once when entering the area varying between 5€ - 20€, and/or parking price ranging between 5€/h - 20€/h. In all scenarios, residents of the site are not charged. Each simulation run takes about 2 hours.

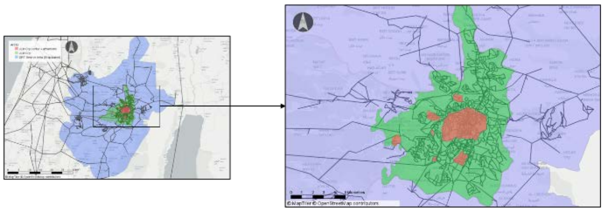
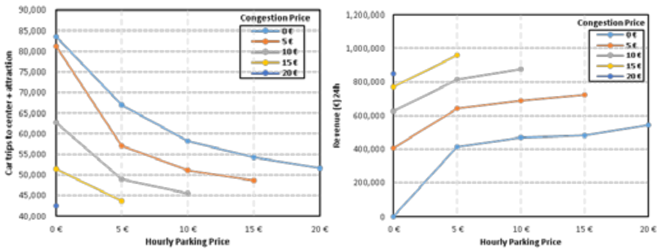


Figure 4. JMA (violet), the city of Jerusalem (green), Jerusalem city center, and close attractive areas chosen for establishing congestion and parking prices (red); distant (left) and close (right) zoom;

Figure 5 shows a comparison between scenarios. It can be seen that car trips (Figure 5a) are decreasing with a higher pricing scheme, and mixing parking and congestion pricing does not have an additional effect on that reduction. Average dwelling time at activities decreases with the increase in hourly parking prices, and even a minimal parking price (5€) reduces the dwelling time by at least 1 hour for any congestion charge. The percentage of congested links (Figure 5d) is two times low (0.93%) for 5€ hourly parking prices compared to the scenario without parking prices and similar to the effect of 10€ congestion charges.



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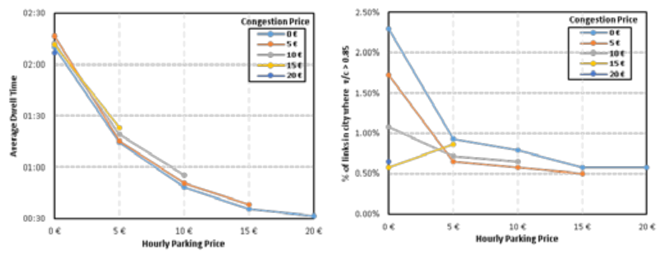

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Figure 5. The major characteristic of the traffic in Jerusalem center as dependent on congestion charge and hourly parking prices there. (a) car trips to center and attraction areas; (b) Daily revenue; (c) Average dwell time and (d) Percentage of congested links (V/C > 0.85)

As can be expected, the congestion charge results in a decrease in arrivals but does not cause a reduction of the dwell time, which remains at about 2:15 hours, while parking prices cause a two-fold decrease of the dwell time to 1:15 hours (Figure 6).

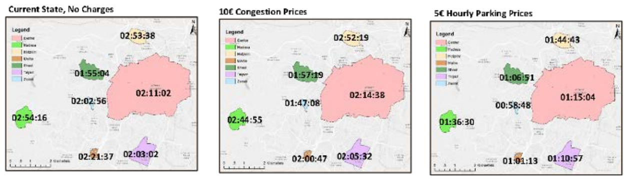

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Figure 6. Dwell time in Jerusalem city center (a) basic scenario; (b) 10€ congestion charge; (c) 5€ hourly parking price

The effects of either congestion charge or parking prices on the modal split are presented in Tables 2 and 3. In both cases, the switch to the PT and walk modes is significant, with a 10% reduction in car use for visiting the city center.

Table 2. The expected modal shift in case of 5€ parking price, no congestion charge.

Parking price/h 0€→€5	Car	PT	Walk
Car	76.3%	19.1%	4.6%
PT	14.0%	84.1%	1.9%
Walk	0.6%	0.5%	98.9%

Table 3. The expected modal shift in case of 10€ congestion charge, no parking prices.

Congestion change 0€→€10	Car	PT	Walk
Car	73.2%	21.0%	5.8%
PT	12.5%	85.7%	1.8%
Walk	0.33%	0.5%	99.2%

4. Discussion

The supply, modal split, and other characteristics of the JMA transportation system are defined by the relative utilities of available transportation modes and marginal utilities of the travel time and transport-related fees for the travelers. The utilities exploited in the JMATSim application result in a very good fit to the traffic data and modal split and entail reasonable policy effect - parking pricing of 5€ or congestion pricing of 10€ will reduce congestion by 25% in the city center.

Urban transportation policy in regards to the congestion charge and parking pricing defines the future of congestion in Jerusalem as well as in other large cities. We demonstrate that a city has two options in this respect: These options are, socially, very different and address different populations: Parking pricing will reduce the dwell time at activities, including shopping and leisure, while congestion pricing will uniformly influence all visitors and does not influence of even enforce longer stay.

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