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Mode Choice Effect on the Number of En-route Travelers and Arrival Rates in an Urban Transport Network

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Abstract Traffic congestion is a challenge facing urban network users and traffic managers worldwide. Although there have been several previous studies conducted to investigate the association between travelers' choices and congestion levels in multimodal transport networks, the effect of mode choice on the number of en-route travelers and the travelers' arrival rates is still largely unknown. Increasing numbers of en-route travelers indicates traffic congestion existence in the network and the efficiency of transportation systems improves as more travelers arrive at their destination. The objective of this paper is to analyze the effects of various mode choice scenarios on the number of travelers staying en-route and arriving at their destination throughout the day in the Sweden national network. To achieve this objective, the multi-agent transport simulation (MATSim) is used as a simulation framework. Specifically, three mode choice scenarios were simulated including a base case to serve as a reference group and 10%, and 30% of agents allowed to change their travel mode. Overall, results revealed that the mode choice flexibility reduced the number of en-route travelers by 44.3% and 37.1%, and the number of travelers reached their destinations has increased by 12.6% and 36.4% for the morning and evening peaks, respectively. The reduced number of travelers still en-route and the increased arrival rates indicate a significant reduction in congestion levels at the network level.

Keywords: Agent-based Modeling; MATSim; Mode Share Ratio; Traffic Congestion; Travel Choices.

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1 Introduction

The rapid expansion of urban areas has led to a significant rise in travel demand and private vehicle ownership [1]. However, the existing infrastructure has not been able to keep up with this growing demand [2], resulting in traffic congestion [3], increased emissions and air pollution [4], climate and environmental changes [5], and a higher rate of accidents [6]. As a consequence of traffic congestion, commuters have been experienced longer delays, increased travel time, and therefore the reliability of the road network has been decreased [7]. Accordingly, the need for an effective, sustainable, and Intelligent Transportation System (ITS) that meets population needs, facilitates the movement of people, goods, and supports environmental well-being has been crucial for modern societies and strong economies [8].

There are several factors impacting the effectiveness and sustainability of transportation systems and the reduction of traffic congestion, includes expanding network infrastructure [9], traffic management strategies [10], and the enhancement of travel behavior [11]. Most importantly, travel choice scenarios, such as mode choices, departure time choices, and route choices, play a crucial role [12]. An increase in the number of en-route travelers indicates the existence of traffic congestion in the network, but the efficiency of transportation systems improves as more travelers arrive at their destination. In this study, the impact of some mode choice scenarios on the level of congestion was investigated and presented in terms of the number of travelers staying en-route, changing departure time from their activity origin, and/or arriving at their destination throughout the day.

Examining the impact of any traffic management strategy before its implementation is crucial for traffic managers and network users. To meet this need, traffic simulation modeling is an effective tool for simulating traffic conditions and supporting intelligent transportation systems [13]. Agent-based transport modeling is a powerful modeling approach commonly used to study traffic management scenarios [14], transport planning

[15], transportation networks analysis [16], dynamic traffic management [17], congestion management [18], traffic signal control [19], and vehicle assignment [20] in large-scale transport networks in reasonable time. In This paper, the multi-agent transport simulation will be used as a simulation framework.

The paper begins with an overview of traffic congestion issues and their negative impacts on transportation systems efficiency. Relatedly, some applications of traffic simulation modeling in transportation studies are presented. Section 2 includes reviewing the effects of travel choice scenarios on the level of congestion, prior research limitations, and an overview of the current study with the simulation framework utilized. In section 3, we describe our methodology and present the data for the case study. Sections 4 and 5 cover respectively the results and conclusion with an emphasis on implications for network operators and policy makers.

2 Effects of Travel Choices on Congestion

There have been several previous studies conducted to investigate the association between travelers' choices and the level of congestion in multimodal transport networks. Some of these studies addressed the proactive route guidance approach to avoid congestion [21], effects of congestion adaptive to travelers' choices on travel and accessibility [22], impact of public bicycle schemes on a congested multimodal transport network [23], and reducing congestion and travel costs in multimodal urban transport networks with limited parking and dynamic pricing [24]. Others investigated the association between mode choice scenarios and travel satisfaction [25], the correlation between the active mode of transportation chosen and the travel behavior exhibited by university students [26], the positive impact of using active transportation modes on public health, climate, and the environment [27], effects of transportation network companies on increasing or decreasing congestion [28], and impact of mixed modes on network efficiency and performance [29].

The increase or decrease in the number of travelers en-route and travelers' arrival rates serve as indicators of congestion at the network level. In more detail, an increase in the number of en-route travelers suggests traffic congestion in the network. Additionally, the efficiency of transportation systems improves as more travelers reach their destination on time. As noted in prior research, there is a gap related to investigating the effect of mode choice on the number of travelers en-route and travelers' arrival rate. Thus, in the current study, the effects of various mode choice scenarios on the number of travelers remaining en-route and those arriving at their destination will be investigated. The Multi-Agent Transport Simulation (MATSim) serves as the simulation framework for this study.

3 Methodology and Study Network

3.1 Multi-Agent Transport Simulation (MATSim)

MATSim is an open-source, agent-based tool that utilizes an activity-based iterative approach, scoring and replanning iterations, and a co-evolutionary algorithm. It is written in Java language and is designed for simulating large-scale transport scenarios. MATSim employs a co-evolutionary algorithm to facilitate interaction among agents. In MATSim, each agent iteratively optimizes its daily activity plan schedule in coordination with all other agents on the transport network infrastructure [30]. This iterative process is a cycle of route assignment but extends beyond it by incorporating additional choice dimensions such as time choice [31], mode choice [32], and destination choice [33] into the MATSim loop as illustrated in Fig. 1.

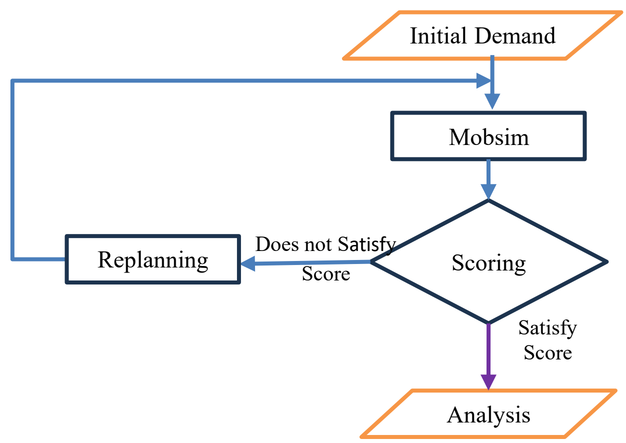


Fig. 1 MATSim Iterative Loop or Cycle.

The agent-based transport modeling approach is employed to analyze travelers' choices in the Sweden national network. Specifically, the paper investigates the impact of using two different mode choice scenarios on the number of en route travelers and travelers' arrival rates, compared to a base case condition, using the MATSim framework. Table 1 presents the mode choice scenarios and the percentages of agents allowed to change their transport mode in each case. Two scenarios are studied: one allowing 10% of travelers to change their transport mode (M10%) and another allowing 30% of travelers to do so (M30%). The reason for selecting 10% of agents to change their mode is that it is the default value in MATSim for replanning. On the other hand, 30%

is chosen to ensure a marked difference in the impact of mode choice.

Table 1 Cases of Mode Choice Scenarios.

Travel Choice	Cases	Case Sample	Percentage of agents allowed to change their transport mode
Mode Choice Scenarios	Base Case	BC	0%
	Case 1	M10%	10%
	Case 2	M30%	30%

3.2 Case Study

Table 2 illustrates the properties of the Sweden National Network considered in this study, including the network size, transportation modes, and population numbers. Additionally, it presents the characteristics of the simulation environment, such as the number of iterations, runtime period, and the type of computing device used.

Table 2 Networks and Simulation Properties.

Case Study	Sweden National Network
Number of Links	552,305
Total Length (km)	873085
Modes	Car, Public transport (Pt), Truck, Pike and Walk
Population	4876200
Iterations	100
Runtime	4 hr.45 min.
Simulation Tool	Workstation

4 Results and Discussion

In this paper, we analyzed how travelers' choices impacting en-route travel and travelers' arrival rates in the simulated Sweden national network. Specifically, we investigated the impact of various mode choice scenarios on the number of travelers staying en-route and arriving at their destination throughout the day. This analysis is conducted based on different mode share ratios and is compared with a base case. Before illustrating the results for the Sweden national network, the mode share ratios resulted from simulating three different mode choice scenarios are discussed.

4.1 Mode Statistics

Table 3 presents the mode share ratio of the different transport modes for the simulated cases; a base case without allowing any mode choice for the agents, allowing mode choice re-planning probabilities for 10% and 30% of the agents. Simulation results show a reasonable change in mode share ratios of different scenarios. Figure 2 presents the mode share ratios for different transport modes under different mode choice scenarios (BC, M10%, and M30%). The x-axis represents the different transport modes, and the y-axis represents the percentage of mode share ratios.

Table 3 Mode Share Ratios for Each Transport Mode.

Mode Type	Mode Share Ratio		
	Base Case (BC)	Case 1 (M10%)	Case 2 (M30%)
Car	75.2%	24.3%	23%
Pt	8.3%	9.0%	8.7%
Truck	4.5%	4.5%	4.5%
Bike	2.2%	47.5%	50.7%
Walk	9.8%	14.7%	13.1%

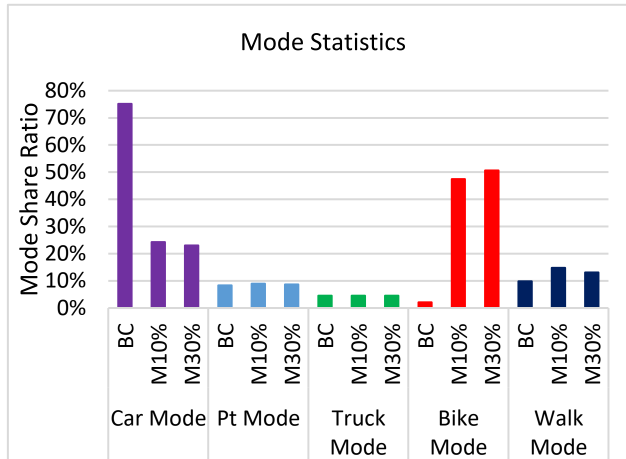
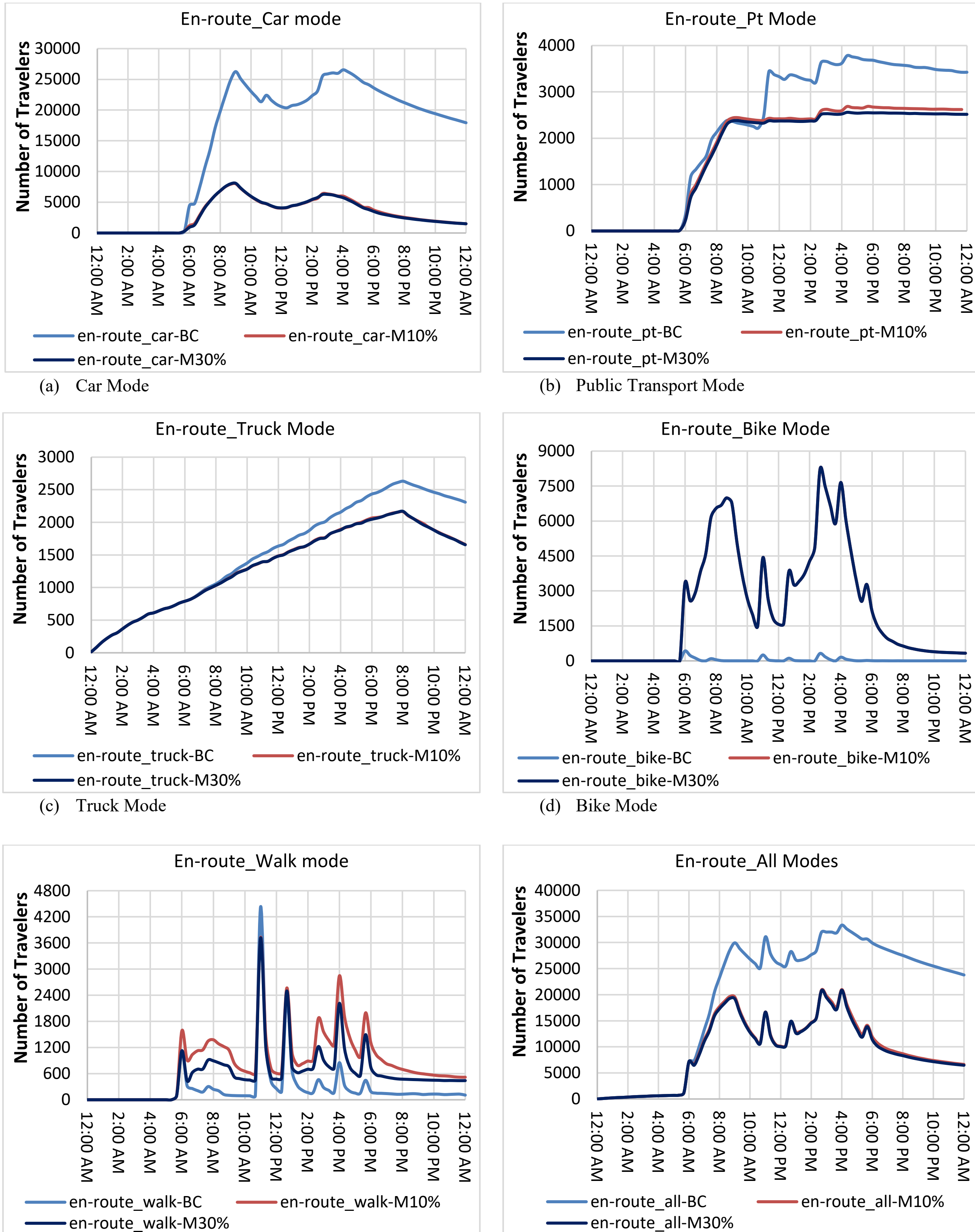


Fig. 2 Mode Share Ratios for Each Transport Mode.

As shown in Fig. 2, the car share ratio is reduced to 24.3% and 23% in case M10% and M30% respectively, compared to 75.2% in the base case. There is no inclination among people to change from their private cars to public transport, as indicated by the percentage of public transport usage in different mode choice scenarios. People who use the truck mode do not have the luxury of choosing their travel mode since they are always drivers – a pattern was noted in all results. Therefore, the truck share ratio remains constant at 4.5% across all mode choice scenarios. The percentage of bike mode has increased significantly from 2.2% in the base case to 47.5% in case M10% and 50.7% in case M30%. Similarly, in walk mode, there was a slight increase from 9.8% in the base case to 14.7% in Case M10%, then a decrease to 13.1% in Case M30%.

4.2 Number of Travelers En-route Per Mode

Increasing the number of en-route travelers indicates traffic congestion existence in the network. The number of travelers who still en-route has been calculated every 20 minutes throughout the day, serving as an indicator of the level of congestion. The number of en-route travelers for each mode of transportation in the network is determined based on each mode choice scenario and subsequently compared with the base case.



(a) Car Mode

(b) Public Transport Mode

(c) Truck Mode

(d) Bike Mode

(e) Walk Mode

(f) All Modes

Fig. 3 Number of Travelers En-route Per Mode

As shown in Fig. 3(a), there are two peaks in car mode at 9:00 AM and 4:00 PM. According to the car share ratio, the number of travelers still en-route was reduced from 26,260 in the base case to 8,020 travelers in case M10% during the morning peak, and from 26,550 to 5,750 travelers during the evening peak. There are no significant changes among the M10% and M30% cases for both peaks meaning that allowing more than 10% of travelers to change their transport mode does not provide additional improvements in travel behavior in the network.

There are slight changes in the public transport share ratio during peak hours in all cases (11:20 AM and 4:20 PM). As shown in Fig. 3(b), the number of travelers distributed throughout working hours has also reduced from 3,440 in the base case to 2,430 in cases M10% during the morning peak, and from 3,780 to 2,685 during the evening peak for the same cases. Moreover, allowing more than 30% of travelers to change their transport mode resulted in small changes in the public transport share ratio compared to M10% case for both peaks.

As mentioned in the description of Figure 2, people using the truck mode do not change their travel mode. Consequently, the truck share ratio remains constant at 4.5% across all mode choice scenarios. However, the number of travelers has decreased from 2,631 in the base case to 2,165 travelers in case M10% during the peak hour (8:00 PM) as shown in Fig. 3(c). This reduction indicates an improvement in congestion at the network level, according to the constant truck share ratio.

For bike mode, the number of travelers also increased significantly from 425 to 6,991 during the morning peak and from 318 to 8,216 during the evening peak as shown in Fig. 3(d). This increase indicates a significant improvement in the use of active travel modes.

Figure 3(e) shows that the number of travelers of walk mode reduced from 4,430 in the base case to 3,728 in cases M10% and 3,715 in case M30% during the morning peak. Additionally, it increased from 851 to 2,480, then decreased to 2,210 during the evening peak for the same cases respectively.

The number of travelers for all transportation modes has been calculated as the summation of travelers across the entire network. The peak hours are 9:00 AM and 4:00 PM in all cases. The number of travelers was reduced from 29,940 in the base case to 16,675 in cases M10% and M30% during the morning peak, and from 33,335 to 20,980 during the evening peak for the same cases, as shown in Fig. 3(f).

To conclude, the mode share ratio for each transportation mode has an effective association with the number of travelers still en-route at the network level. As illustrated in Fig. 3(f), the number of travelers has decreased by 44.3% and 37.1% for the morning and evening peaks, respectively. This reduction indicates a significant improvement in the level of congestion at the network level.

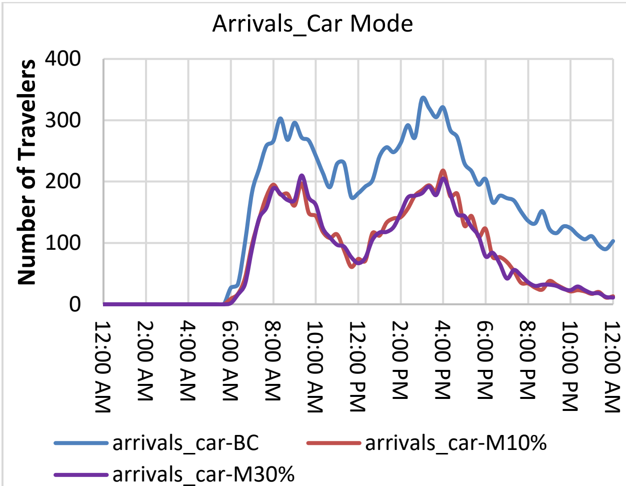
4.3 Travelers' Arrival Rate Per Mode

The efficiency of transportation systems improves as more travelers reach their destinations. In this study, the number of travelers arriving at their destinations has been calculated every 20 minutes throughout the day, serving as an indicator of congestion levels. The number of travelers arrived at their destination for each mode of transportation in the network is determined based on each mode choice scenario and subsequently compared with the base case.

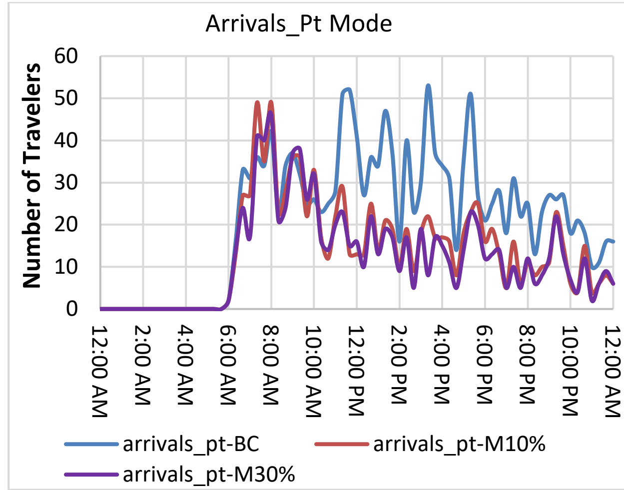
As shown in Fig. 4(a), there were two peaks in car mode, around 9:00 AM and 4:00 PM. According to the reduction in car share ratio with mode choice scenarios, the number of travelers arriving at their destinations decreased from 296 in the base case to 191 in case M10% during the morning peak and from 321 to 218 during the evening peak. The car mode has the least gaining from arrival rate improvements which may encourage people to shift to other modes toward decreasing the use of motorized transportation modes. There is no significant change between M10% and M30% cases for both peaks, indicating that allowing more than 10% of travelers to change their transport mode does not improve travel behavior in the network.

There are slight changes in the public transport share ratio during peak hours in all cases (11:20 AM and 5:20 PM). As shown in Fig. 4(b), the number of travelers distributed throughout working hours has also reduced from 51 in the base case to 29 in case M10% during the morning peak, and from 51 to 25 during the evening peak for the same cases. Allowing more than 30% of travelers to change their transport mode resulted in small changes in the public transport share ratio compared to the M10% case for both peaks.

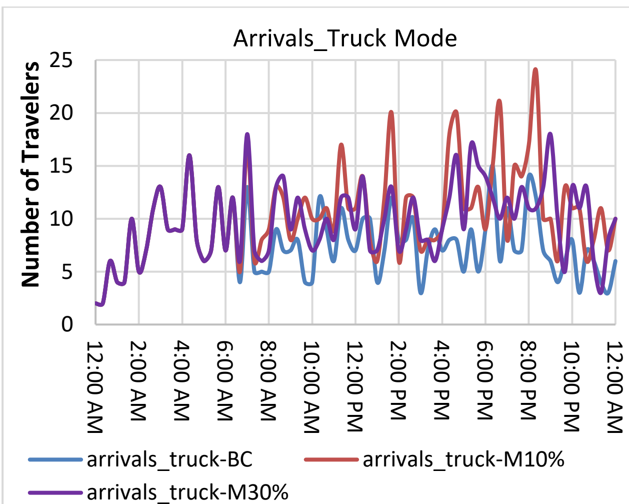
Although the truck share ratio remains constant at 4.5% across all mode choice scenarios, the number of travelers arriving at their destination has increased from 14 in the base case to 24 travelers in case M10% during the peak hour (8:20 PM) as shown in Fig. 4(c). This increase indicates an improvement in the level of congestion at the network level.



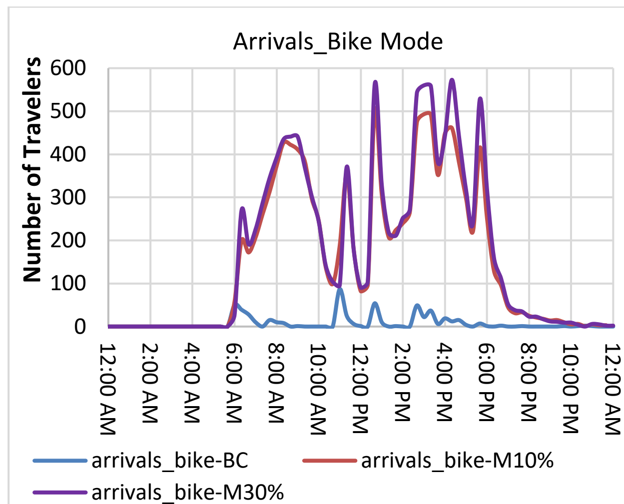
(a) Car Mode



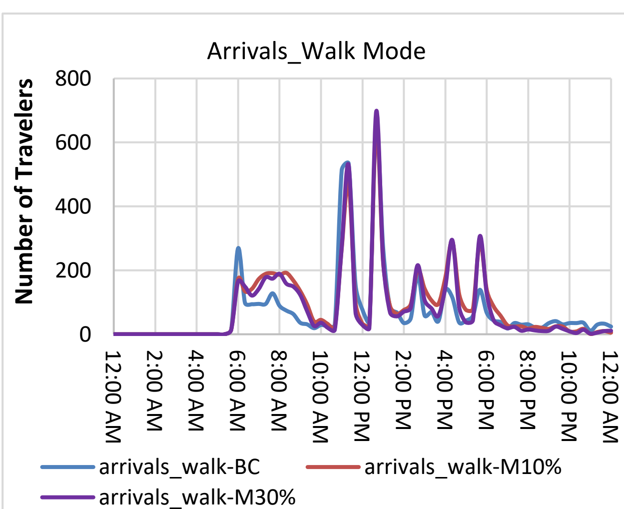
(b) Public Transport Mode



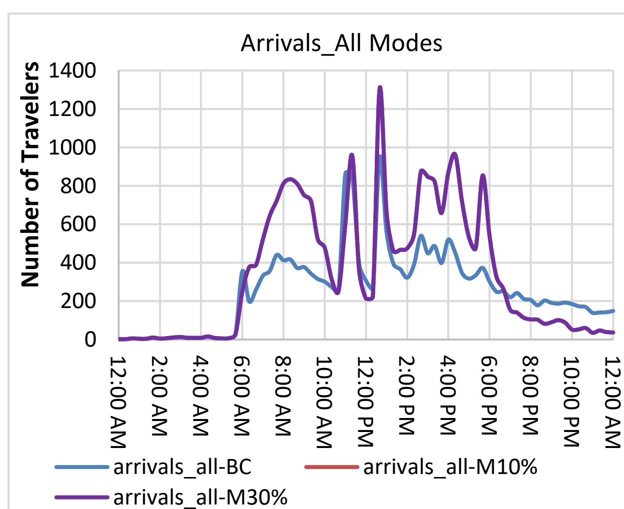
(c) Truck Mode



(d) Bike Mode



(e) Walk Mode



(f) All Modes

Fig. 4 Travelers’ Arrival Rate Per Mode

According to the constant truck share ratio, this indicates the social benefits for people who do not change their transportation mode but gained an improvement in the level of congestion at the network level.

For bike mode, the number of travelers also increased significantly from 15 to 373 during the morning peak and from 54 to 503 during the evening peak as shown in Fig. 4(d). This increase indicates a significant improvement in the use of active travel modes (bike mode) with a significant increase in the number of travelers arriving at their destination.

Figure 4(e) shows that the number of travelers of walk mode reduced from 534 in the base case to 471 in cases M10% then increased again to 529 in case M30% during the morning peak (11:20 AM). Additionally, it increased from 647 to 655, and 697 travelers during the evening peak (12:40 PM) for the same cases respectively.

The number of travelers for all transportation modes has been calculated as the summation of travelers across the entire network. The peak hours are 11:20 AM and 12:40 PM in all cases. The number of travelers arriving at their destination increased from 851 in the base case to 958 in cases M10% and M30% during the morning peak, and from 949 to 1307 travelers during the evening peak for the same cases, as shown in Fig. 4(f).

To conclude, the mode share ratio for each transportation mode has an effective association with the number of travelers arriving at their destination at the network level. As illustrated in Fig. 4(f), the number of travelers increased by around 12.6% and 36.4% for the morning and evening peaks, respectively. This increase in arrival rates indicates a significant reduction in the level of congestion at the network level.

4.4 Travelers Departure Rate Per Mode

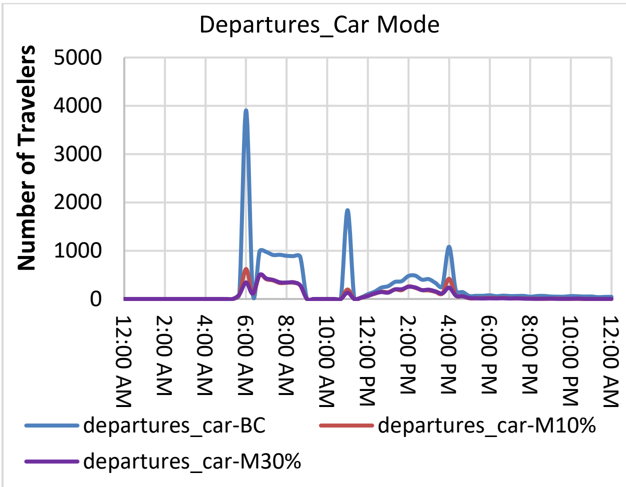
Figure 5(a)-(f) shows the departure time shift of the transport mode users for the simulated cases; a base case without allowing any mode choice for the agents, allowing mode choice re-planning probabilities for 10% and 30% of the agents. Simulation results show no reasonable change in users' departure time of different scenarios.

5 Conclusion

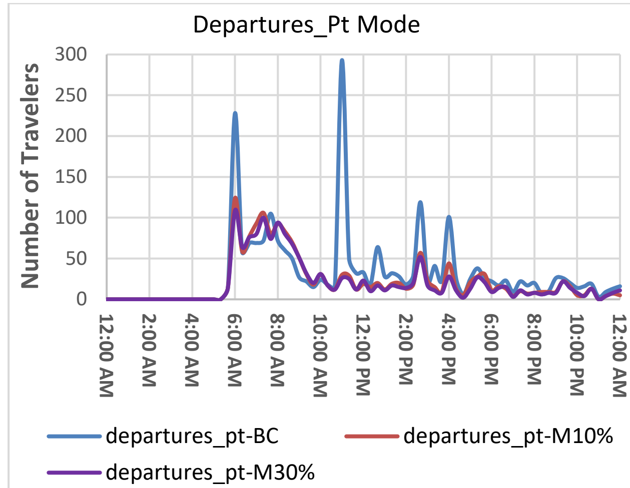
Based on the results obtained in the present paper, according to the change in mode share ratio for each transportation mode, the number of travelers who still en-route for all modes of transportation has been significantly reduced for the morning and evening peaks. This reduction indicates an improvement in the level of congestion at the network level. There are some major conclusions which include the following:

- There is no inclination among people to change their private cars to public transport, as indicated by the percentage of public transport usage in mode share ratios which matching with the literature results [25].
- According to the mode share ratios, people prefer to use active modes (biking and walking) over motorized modes (cars and public transport). This is what governments and policy makers encourage to reduce congestion, improve public health, and safeguard the environment [26].
- Reduction in the number of travelers still en-route and Increased arrival rates for all modes of transportation indicate a significant improvement in congestion severity at the network level.

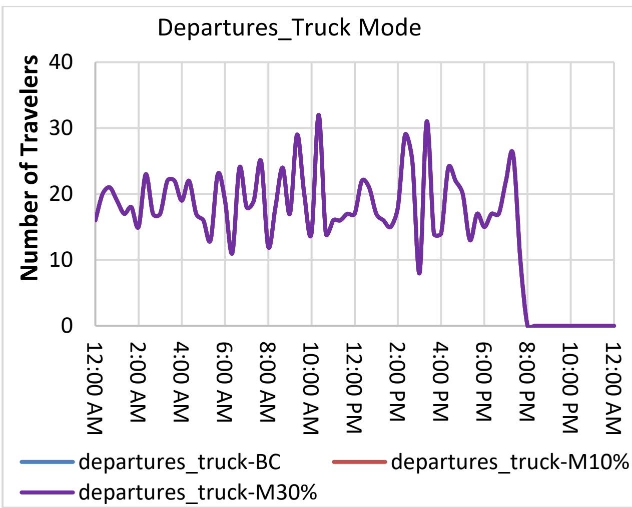
It can be concluded that the mode choice scenarios effectively impact the number of travelers still on their routes and those who have arrived at their destination. Due to mode choice permission, the number of en-route travelers has been reduced by around 55.7% and 62.9% for the morning and evening peaks, respectively. This reduction indicates an improvement in the level of congestion at the network level. Otherwise, mode choice permission has not affected users' departure time. Future research may consider the combination between mode, route and departure time choices that may have an impact in travel behavior toward decreasing traffic congestion from the network level point of view.



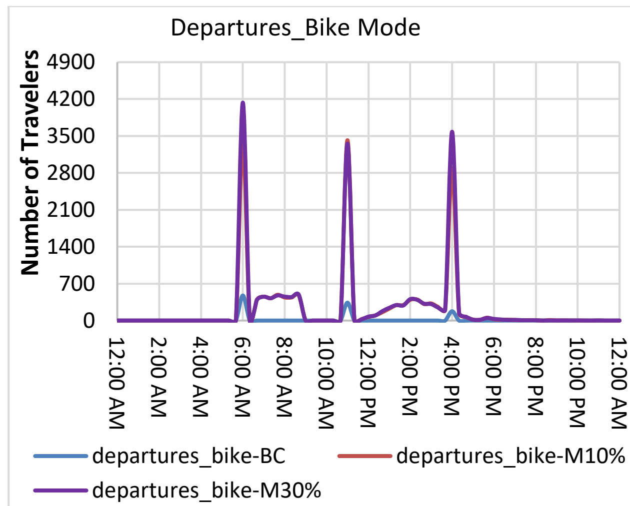
(a) Car Mode



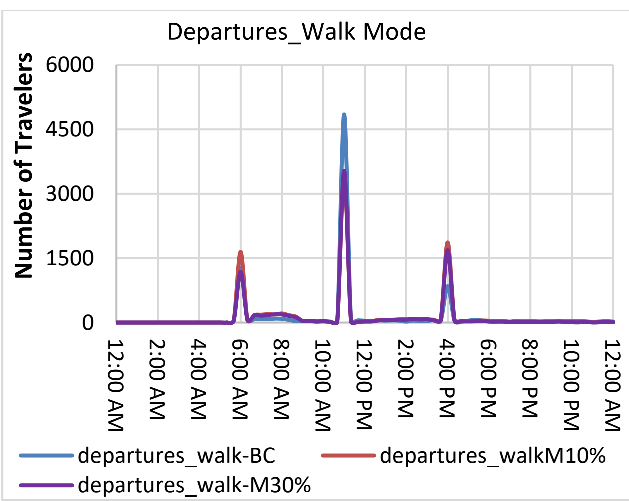
(b) Public Transport Mode



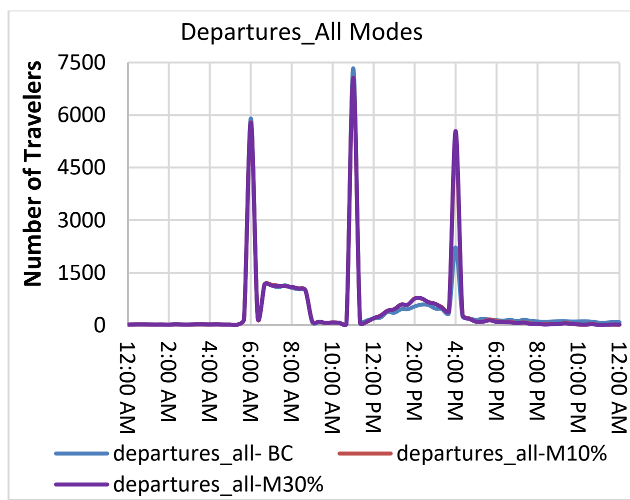
(c) Truck Mode



(d) Bike Mode



(e) Walk Mode



(f) All Modes

Fig. 5. Travelers Departure Rate Per Mode

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