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Research Article

A case study on the impact of Micromobility on Four-Arm Signalized Intersection Performance

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ABSTRACT

With increasing urbanization, problems such as traffic congestion and environmental pollution have become more pronounced. Alternative modes of transportation such as micromobility (bicycles, e-scooters, e-bikes, segways) have the potential to reduce these problems. This study analyzes the effects of micromobility on the performance of an intersection using a simulation-based approach. A four-arm signalized intersection in Nilüfer, Bursa, is taken as a model, and the impact of micromobility on intersection performance is evaluated in terms of "average vehicle speed", "queue delay", and "vehicle travel time" performance indicators. In the study, the inclusion of micromobility at low levels (2.5% and 5%) improves intersection performance, while at higher levels (7.5% and 10%) this improvement is reversed, resulting in longer travel times and lower speeds. Signal modification has shown an improvement in the performance of the intersection. However, these results suggest the need for special signaling studies for micromobility vehicles at intersections. The study provides important findings for transportation management and policy makers in micromobility planning.

1. Introduction

The increase in urban populations leads to transportation problems such as traffic congestion, environmental pollution and stress. Transportation has a major impact on air pollution; 80% of air pollution in Asian cities is caused by transportation [1]. In addition, private car use reduces people's physical activity, leading to unhealthy lifestyles. Therefore, transportation policy makers are working to reduce these negative impacts. In particular, they effort focus on reducing traffic congestion and encourage people to public transportation and micromobility (bicycles, e-scooters, etc.) solutions. Reducing the use of private cars in cities and promoting environmentally friendly modes of transportation are the basis of sustainable transportation policies [2-4]. Multimodal and personalized transportation services are being developed with solutions such as Mobility as a Service (MaaS) [6,7].

Micromobility can contribute to improving the coverage of public transport services by replacing short-distance trips (e.g. daily round trips) made by private vehicles [1,7]. Comi and Polimeni [1] note that micromobility is an important lever supporting the transition from motorized modes of transport. In this context, traffic simulations are required to assess the impact of micromobility in a mixed traffic environment and its contribution to sustainability [8].

Studies on micromobility have focused on different areas. Some studies examine how micromobility promotes the transition to zero-emission sustainable modes of transportation [9]. Other studies have focused on cultural, legal and political factors that may hinder the use of this environmentally friendly transportation [10]. The environmental performance of micromobility has been addressed through life cycle assessment [11,12], with [12] comparing shared and private micromobility. Sun and Ertz [11] emphasized that the low utilization rates of shared micromobility are not enough to reduce emissions and stated that more incentive policies are needed. In addition, it is possible to come across some studies on the effects of micromobility on traffic safety in the literature. Asensio et al. [13] stated that some cities have banned MM vehicles due to personal safety and other concerns. Comi et al. [14] stated that the absence of any restrictions for MM users is a threat to traffic safety and that appropriate traffic regulations and education programs should be made for MM users. According to a study conducted in Lithuania by Asiūnienė and Tumavičė [15], e-scooter users increased the number of accidents by 58.06% between 2019 and 2020, and nearly 65% of them were involved in accidents with motor vehicles. They observed that accidents mostly occurred at intersections and pedestrian crossings.

For this purpose, this study investigates the changes in intersection performance when micromobility vehicles are included in the traffic. For this, the current situation is analysed in the traffic simulation program (PTV VISSIM). Then, bicycles, e-bikes, e-scooters and segways, which are micromobility vehicles, are modelled in the simulation program and included in the study. Roller skates, push scooters, hoverboards, solowheels, etc. are not included in this study due to their low usage and very rare occurrence in traffic. Intersection performance is considered in terms of queue delay, average vehicle speeds and travel times. The second section of the paper presents the methodology, the next section presents the results, and the fourth section presents the conclusions.

2. Material and Methods

In this study, we investigate the changes in the performance of an intersection when non-motorized vehicles, i.e., micromobility vehicles, are substituted for the travel demands of a certain proportion of motorized vehicles in normal traffic. For this purpose, Uğur Mumcu intersection (400 13' 13" N, 280 54' 53" E) in Özlüce district of Nilüfer county of Bursa province is selected as a field study (Fig. 1). This intersection is chosen because it is close to the main arteries and signalizations are planned for pedestrian crossings.

Figure 1: View of Uğur Mumcu signalized interseciton

This signalized four-arm roundabout type intersection has traffic lights inside the intersection in addition to the approach arms. Yüzüncüyıl (YY) and hospital arms are two lanes, Özlüce and İzmir arms are three lanes. Lane widths are 3.5m. At this intersection, 15-minute video recordings are taken on weekdays between 17:00-18:00 on Friday (08.03.2024), which is the peak hour. The video recordings are analyzed and vehicle counts are made to determine the traffic volumes and vehicle composition at the intersection arms, as well as the vehicle flow rates. Signalization times of the intersection are obtained from Bursa Transportation Coordination Center (UKOME). VISSIM, a traffic simulation program, is used to analyze the behavior of micromobility vehicles and their impact on the intersection. The flowchart of the study is given in Fig. 2.

2.1. Substitution of micromobility vehicles for motorized vehicles

In the study, existing vehicle compositions will be replaced by micromobility vehicles. This requires the number of passengers in various vehicle classes to be known. Thus, micromobility vehicles will be added to the simulation network according to the number of vehicles and, thus, the number of passengers pulled from the intersection.

Table 1: Occupancy rates and number of trips by vehicle composition

	Car	Bus	Minibus	Service	Truck	Motorbike	Total
Yüzüncüyıl (YY)							
Vehicle rate (%)	91	0.7	3	0.7	1.1	3	100
Vehicle Number of Vehicle	888	7	29	7	11	32	974
Occupancy rate	1.6	28.2	28.2	12.14	1	1	
Number of trips	1421	198	818	99	11	32	2579
Trip rate (%)	55	7.6	32	3.9	0.4	1.2	100
Özlüce							
Vehicle rate (%)	82.57	0.27	4.46	3.38	5.00	4.32	100
Vehicle Number of Vehicle	1222	4	66	50	74	64	1480
Occupancy rate	1.6	28.2	28.2	12.14	1	1	
Number of trips	1955	113	1861	607	74	64	4674
Trip rate (%)	41.82	2.41	39.8	12.98	1.58	1.36	100
Hospital							
Vehicle rate (%)	87.43	0.40	2.57	3.76	1.39	4.46	100
Vehicle Number of Vehicle	883	4	26	38	14	45	1010
Occupancy rate	1.6	28.2	28.2	12.14	1	1	
Number of trips	1413	113	733	461	14	45	2779
Trip rate (%)	50.83	4.05	26.38	16.59	0.50	1.62	100
İzmir							
Vehicle rate (%)	87.05	0.11	2.91	3.75	4.03	2.13	100
Vehicle Number of Vehicle	1553	2	52	67	72	38	1784
Occupancy rate	1.6	28.2	28.2	12.14	1	1	
Number of trips	2484	56	1466	813	72	38	4931
Trip rate (%)	50.39	1.14	29.73	16.49	1.46	0.77	100

The number of passengers in a vehicle indicates its occupancy rate. While each vehicle type has different occupancy rates, this varies according to different travel types, travel timing, countries and regions, the number of vehicles in the household, and even income. There are many studies in the literature on the determination of vehicle occupancy rates.

Barton-Aschman Associates [16] found that the lowest vehicle occupancy rates are associated with home-to- work travel. The National Travel Survey 2010-2012 found that vehicle occupancy rates vary by trip purpose, being lowest for commuting and work (1.2 passengers/vehicle) and highest for vacations/day trips and education (2 passengers/vehicle). In studies, vehicle occupancy rates vary from country to country. According to the European Environment Agency (EEA 2010), in Eastern European countries such as the Czech Republic, Slovakia and Hungary, it is 1.8 passengers per vehicle (1.4 passengers per vehicle in the Czech Republic, 2 passengers per vehicle in Slovakia and 1.9 passengers per vehicle in Hungary, respectively). A study led by a World Bank team (2010) found that vehicle occupancy rates for passenger cars, pickups, motorcycles, taxis, microbus, minibuses and buses in Cairo were 1.5, 1.3, 1.0, 2.5, 13, 21 and 49 passengers/vehicle respectively.

In this study, the vehicle occupancy values of the Istanbul Transportation Master Plan [17] are used for vehicle occupancy rates (Table A1), since they refer to the same country/region and similar working hours. For this purpose, travel data are collected from 9 different regions and occupancy values are determined by dividing the total number of passengers by the number of vehicles. In terms of vehicle volumes, the number of motor vehicles coming from each intersection arm is reduced by 2.5% to 10%. Table 1 shows the number and proportions of micromobility vehicles that should replace motorized vehicles with the percentages mentioned above.

2.2. Simulation study

The fact that urban infrastructure is conducive to the use of micromobility vehicles will, of course, have a significant impact on people's use of these modes of transportation. This also reflects the necessary conditions for sustainable transportation. Studies have been conducted in different cities on how users would change their transportation mode choice behavior in the presence of micromobility infrastructure [1]. In a survey conducted in Paris, Christoforou et al. [18] found that micromobility is used for trips of more than 4 km and less than 15 minutes. It is observed that 21% of these trips are made by motorized vehicles and 35% on foot. In another study in Oslo, 60% of micromobility users walked, 23% used transit systems, 3% used private vehicles and the rest used other modes [19]. In this study, micromobility vehicles such as roller skates and skateboards were not included in the simulation because they are used more for recreational purposes and are much less common than vehicles such as bicycles or e-scooters. In addition, e-scooter and Segway vehicles are not defined in the simulation, so these vehicles are modeled separately and included in the simulation (Fig. 2).

The intersection is modeled in VISSIM [20], one of the most important traffic simulation programs. The maximum value of the 15-minute vehicle count data obtained from traffic counts is entered as hourly volume. The vehicle composition (cars, trucks, buses, motorcycles, service vehicles, etc.) is entered into the program as a proportion of the traffic volume. The directional distribution of vehicles is also specified as relative traffic flow (see Table A2). The flowchart of the simulation model is shown in Fig. 3. The design started with the simulation modeling of urban and bicycle roads with micromobility vehicles and continued with the tuning of the driving behavior parameters of the micromobility (MM) vehicles, which is described in detail at the end of this section.

In the VISSIM simulation program, the driving behavior parameters of the vehicles are specified with Wiedemann 99. The acceptable error difference between the observed values of the driving behavior parameters and the simulation results should be within 15% [21,22]. A total of four data collection points are set up, one at each exit point of the intersection arms, considering the traffic counts every 15 minutes passing through the intersection arms (Fig. 4a).

The simulation run is run 10 times with different seed numbers (42 random seeds and 51 random seed increments) after each calibration run of the driving behavior parameters. The resolution of the simulation is set to 0.1 seconds (see Fig. 3). In addition, since the presence of signals inside the island at the intersection changes the simulation values considerably, and to get closer to the observed values, these signals inside the island (5,6,7, and 8 signals, see Fig. 4 b) are removed.

The error between 15-minute traffic volumes is considered as the margin of error (MOE). The percentage error between simulated data and field observed data for the data collection points specified at the intersection is calculated using Equation (1);

$$\%\ Error = (OTV - STV)/OTV \qquad (1)$$

where:

OTV: Observed traffic volume

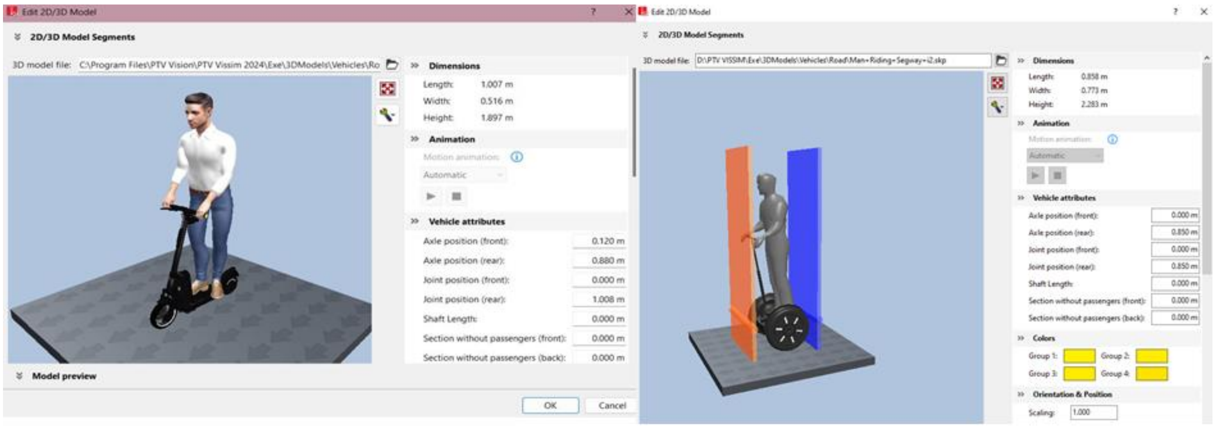
STV: Simulated traffic volume

Lewis [23] reported a good fit for MAPE between 10% and 20%, but excellent for MAPE values below 10%.

Mean absolute percentage error (MAPE), one of the goodness-of-fit indices, is used to find the difference in error between the observed values and the simulated values according to the calibration.

$$MAPE = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{(x_i - \hat{x}_i}{x_i}\right| * 100 \qquad (2)$$

where, N is the total number of traffic measurement observations, x and $\hat{x}$ are, respectively, observed and simulated data points at a time-space domain. In addition, Table 2 shows the MAPE results between the traffic data obtained from the field and the simulated data.



3D model file: C:\Program Files\PTV Vision\PTV Vissim 2024\Exe\3DModels\Vehicles\Ro

Length: 1.007 m
Width: 0.516 m
Height: 1.897 m

Axle position (front): 0.120 m
Axle position (rear): 0.880 m
Joint position (front): 0.000 m
Joint position (rear): 1.008 m
Shaft Length: 0.000 m
Section without passengers (front): 0.000 m
Section without passengers (back): 0.000 m

3D model file: D:\PTV VISSIM\Exe\3DModels\Vehicles\Road\Man+Riding+Segway+i2.skp

Length: 0.858 m
Width: 0.773 m
Height: 2.283 m

Axle position (front): 0.000 m
Axle position (rear): 0.850 m
Joint position (front): 0.000 m
Joint position (rear): 0.850 m
Shaft Length: 0.000 m
Section without passengers (front): 0.000 m
Section without passengers (back): 0.000 m

Scaling: 1.000

Figure 2: Modeling vehicles of e-scooter and segway at VISSIM.

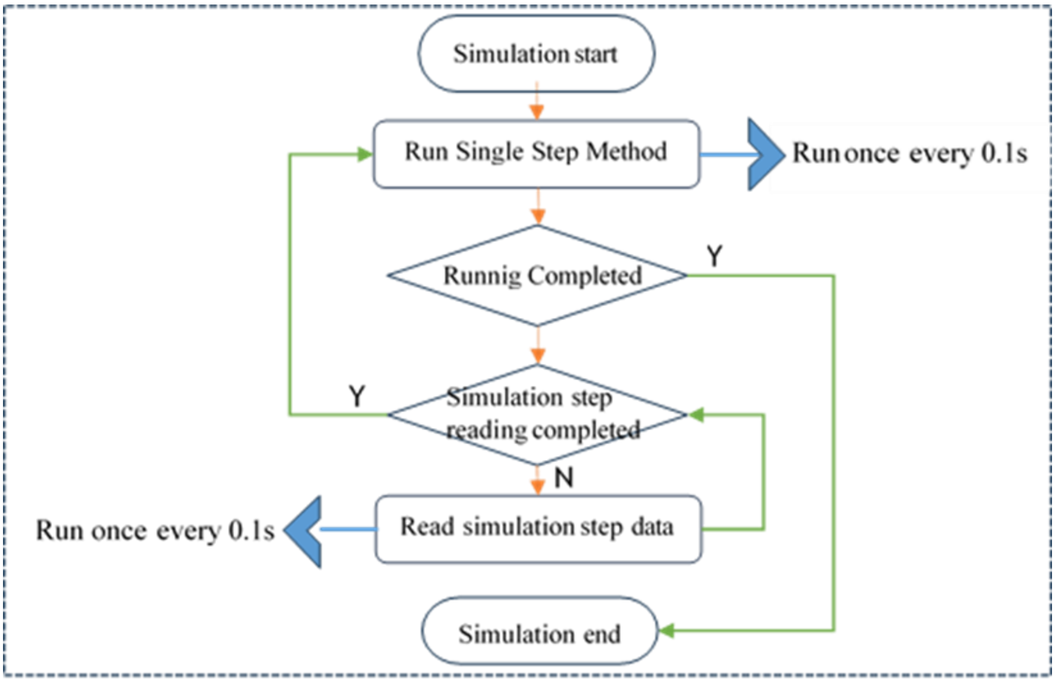
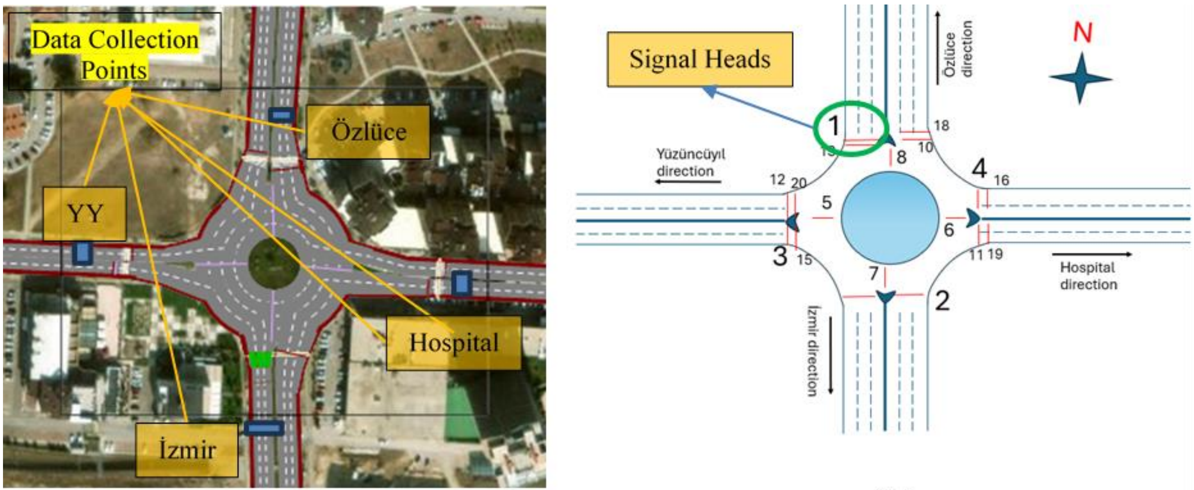


Figure 3: Simulation run update flow chart.



(a) (b)

Figure 4: Data collection points on the intersection (a) and signal heads (b).

Table 2: MAPE values according to observed datas and simulated results at Uğur Mumcu intersection

Data Collection Points	Time interval	OTV	STV	% Error	MAPE (%)
1	17:00-17:15	222	194	0.13	5.53
	17:15-17:30	244	239	0.02	
	17:30-17:45	229	229	0.00	
	17:45-18:00	266	246	0.08	
2	17:00-17:15	342	334	0.02	8.32
	17:15-17:30	382	345	0.10	
	17:30-17:45	417	341	0.18	
	17:45-18:00	337	351	-0.04	
3	17:00-17:15	213	184	0.14	9.18
	17:15-17:30	228	218	0.04	
	17:30-17:45	249	212	0.15	
	17:45-18:00	214	227	-0.06	
4	17:00-17:15	460	339	0.26	9.36
	17:15-17:30	481	440	0.09	
	17:30-17:45	471	419	0.11	
	17:45-18:00	419	423	-0.01	

In addition, the driving behavior parameters of e-bicycle, e-scooter and segway vehicles are also modeled for the bicycle driving behavior parameters of the simulation program. In previous studies, acceleration and deceleration and average speeds for comfortable, sudden and unexpected situations for these vehicles are examined [24-26]. In this study, the acceleration and deceleration acceleration values of e-bicycle, e-scooter and segway vehicles are based on the findings of [24] (Table 3). The design of the bicycle lanes in the simulation is modeled to be right next to the normal roadway and at a separate service level from this roadway and their width is arranged to be 1.5m (T.S 9826).

3. Results and Discussions

A microsimulation program is used to evaluate the intersection performance. Average speed, vehicle travel time and queue delay are selected as performance metrics. Fig. 5 shows the simulation results at different arms of the intersection according to the scenario where motor vehicles are removed from the traffic at certain rates and micromobility vehicles (MM) are included. Fig 5(a) shows how the average speeds change with the increase of micromobility vehicles. At Yüzüncüyıl (YY), Hospital and İzmir, there is an increase in the average speed of the vehicles because of removing up to 7.5% of motor vehicles from the traffic and replacing them with the micromobility vehicles shown in Table 4. However, as more motor vehicles are withdrawn from traffic and replaced with MM vehicles (-10%), there is a steady decrease in average speeds. At Özlüce, there is a significant decrease in average speed from 5% onwards. This may indicate that the traffic flow at Özlüce is more sensitive to micromobility. In general, it is possible to say that as the proportion of micromobility vehicles in traffic increases, a decrease in average speeds is observed.

Fig. 5b shows how queue delay changes with the increase of micromobility vehicles in traffic. For all locations, the introduction of MCCs up to 5% decreases the queue delay, but when this percentage increases to 7.5% and 10%, it increases the queue delay in the opposite direction and with a high output.

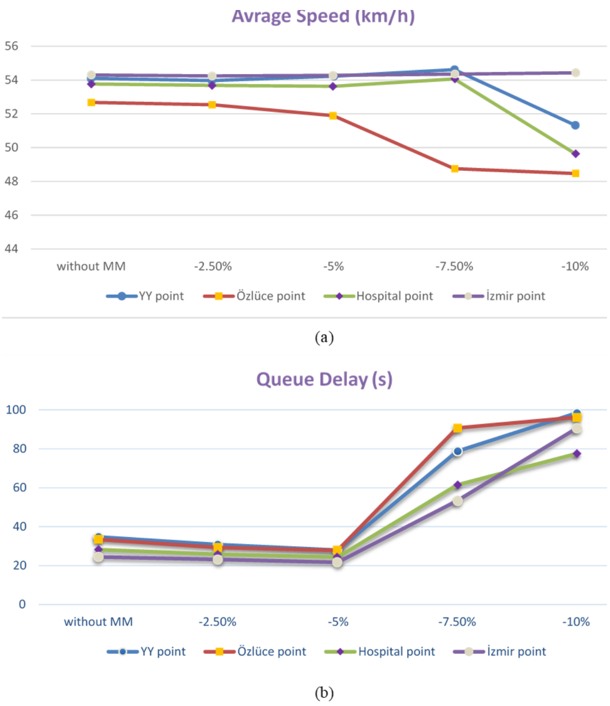


Figure 5: Average speed (km/h) and (b):queue delay

Fig. 6 shows how travel times on different routes change as micromobility vehicles increase in traffic. Each graph reflects the change in travel times for a given direction of travel as motorized vehicles are removed from traffic and replaced by micromobility vehicles. Fig. 6a shows the travel times of vehicles from YY to Hospital, İzmir and Özlüce, and shows an increase in travel times as motorized vehicles decrease and micromobility vehicles increase in traffic. In particular, the travel time to Hospital increases significantly with the increase of 7.5% and 10% of micromobility vehicles. Although there is also an increase in travel times to Izmir and Özlüce, this increase is not as significant as at Hospital. This can be explained by the fact that micromobility vehicles slow down the traffic flow at intersection crossings, thus increasing the travel time.

Table 2: Behavioral parameters used in the study to simulate micromobility vehicles

VISSIM parameters	Reference	Bicycle	e-bicycle	e-scooter	Segway
Acceleration (Comfort) [m/s^2] (CC8)	Doza et al [24]	0.45 ± 0.11	0.70 ± 0.12	0.56 ± 0.19	0.67 ± 0.36
Acceleration (Harsh) [m/s^2] (CC8)	Doza et al [24]	0.76 ± 0.28	0.95 ± 0.14	0.70 ± 0.25	1.01 ± 0.34
Deceleration (Comfort)	Doza et al [24]	-1.50 ± 0.51	-1.65 ± 0.66	-1.28 ± 0.42	-0.93 ± 0.40
Deceleration (Harsh planned)	Doza et al [24]	3.00 ± 0.51	-3.10 ± 1.25	-2.21 ± 0.59	-1.65 ± 0.59
		-3.60 ± 1.28	-3.66 ± 1.07	-2.23 ± 0.71	-1.60 ± 0.49

Fig. 6(b) shows the travel times from Özlüce to YY, Izmir and Hospital. There are significant increases in travel times starting from 5% of micromobility vehicles. Travel time to Hospital shows the largest increase compared to other points as the micromobility rate increases. Travel times to YY and Izmir also increase, but not as dramatically as to Hospital. This graph reveals that the impact of micromobility on travel time is greater, especially in the Hospital direction.

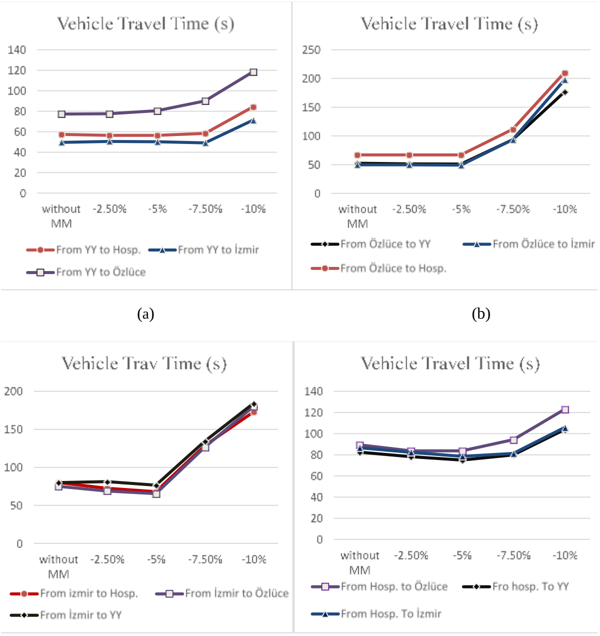
Fig. 6(c) shows a rapid increase in travel times with the increase of micromobility vehicles in traffic, especially from 7.5% onwards. Travel times to Hastane and Özlüce are quite close to each other, and travel times increase almost at the same level with the increase in the micromobility rate. The travel time to YY shows a slower increase. This may indicate that the roads from Izmir to the hospital and Özlüce are more sensitive to micromobility.

Fig. 6(d) shows that travel times to YY and Izmir routes start to increase significantly after a 5% increase in micromobility. The travel time to Özlüce remains at the lowest levels, but reaches a similar level to the other points with an increase in the micromobility rate to 10%. This may indicate that travel times in the direction of the hospital vary less according to the micromobility rate.

It is possible to say that the increase of micromobility vehicles in traffic has significantly increased travel times. However, the response of each route to this change is different; in particular, vehicles traveling in the Hospital direction seem to be more sensitive to the increase of micromobility vehicles in traffic.

This is an indication that the signal durations for pedestrian crossing are not suitable for MM vehicles and a separate signalization study for MM is required.

These performance cases show us that removing motor vehicles from traffic and replacing them with micromobility vehicles, with the occupancy rates of motor vehicles, will not always be beneficial, especially in key areas of road networks, such as intersections. This is because up to 2.5% and 5%, intersection performance in queuing delays, average speeds, and vehicle travel times is found to improve at the current signal level. However, as this ratio increases (after 5%), contrary to expectations, a decrease in these performance criteria is observed. The reason for this can be said to be that the signalization between the intersection arms prevents the passage of motor vehicles. This is because as the proportion of MM vehicles increases in these areas, MMs also create queues on the road, preventing the passage of motor vehicles. This situation is similar at all intersection arms. For this reason, signal optimization studies should be carried out in appropriate places in the current situation.

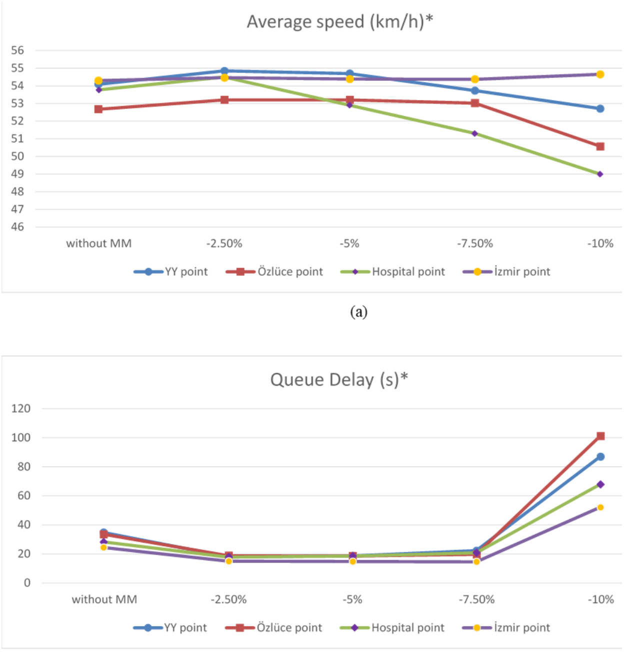


(a) (b)

(c) (d)

Figure 6: Travel time; (a): from YY, (b): from Özlüce, (c): from İzmir, (d): from Hospital

The adjustments in signal timings resulted in significant improvements in performance indicators. Signal timing plans are given in Fig. A1. As shown in Fig. 7, these adjustments optimized the passage times on both main arteries and intersection approaches. As a result, there is a noticeable improvement in all performance metrics. As seen in Fig. 7a, vehicle travel times improved by up to 7.5% MM. Similarly, while the queuing delay in the existing signal timings worsened after 5% MM, the adjusted signal timings showed an improvement of up to 7.5% MM (Fig. 7b). In addition, Fig. 8 shows the change in average speed after signal adjustment. That is, the decrease after 5% MM before signal adjustment increased up to 7.5% MM after signal adjustment. This also improved the performance in each direction of the intersection. To illustrate the improvement in intersection performance, a comparison of the queuing delay results only is given as an example in Table 4.

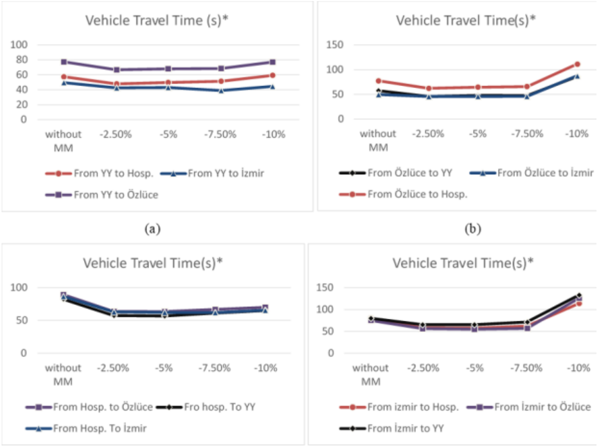


(a)

(b)

*After signal modification

Figure 7: Intersection performance after signal modification, (a):Average speed (km/h), (b): Queue delay



(a) (b)

(c) (d)

*after signal modification

Figure 8: Travel time after signal modification; (a): from YY, (b): from Özlüce, (c): from Hospital, (d): from İzmir

Table 3: Comparisons of queue delay results after adjusting signal duration

	Without MM	-2.50%	-2.50%*	-5%	-5%*	-7.50%	-7.50%*	-10%	-10%*
YY point	34.770	30.792	18.083	27.924	18.712	78.754	22.284	98.413	86.970
Özlüce point	33.496	29.361	18.862	27.871	18.608	90.665	19.728	96.182	101.146
Hospital point	28.235	25.793	17.874	24.350	18.586	61.469	20.825	77.545	67.935
İzmir point	24.475	23.121	15.042	21.711	14.774	53.306	14.594	90.595	52.130

*Considering adjusted signal duration

However, when MM vehicles constitute 10% of the traffic, a sudden deterioration in intersection performance is observed. This occurs because the traffic signals, which regulate the flow between different directions of the intersection, fail to allocate sufficient time for the passage of MM vehicles. As a result, MM vehicles form queues on the roadway, obstructing the movement of motorized vehicles (Fig. 9). This leads to increased queue delays and travel times, while average speeds decrease.

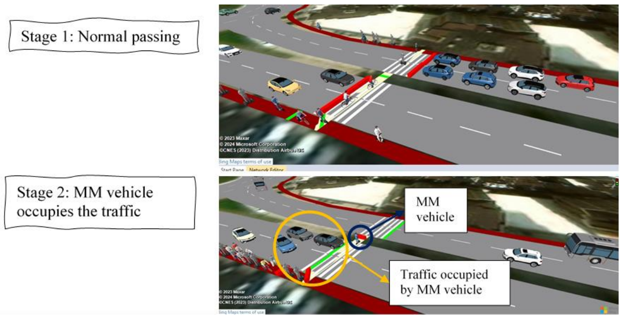


Figure 9: Effecting of MM vehicles on traffic

In the end, it is seen that the performance of intersections, especially MM intersections, can be improved with an adjustment in signal durations, but it is still necessary to conduct a signal optimization study to achieve the best performance.

4. Conclusion

This study investigates changes in an intersection's performance due to micromobility (MM). For this purpose, a four-arm signalized intersection in the Bursa Nilüfer region is modeled in a simulation environment. To analyze the performance of MM vehicles at the intersection, hypothetical bicycle roads are added to the simulation environment, and bicycles, e-scooters, and segway vehicles, which are micromobility vehicles, are also modeled in the simulation environment with driving behavior parameters. The MM equivalent of the area occupied by the vehicles in the traffic is calculated based on the data obtained from previous studies. Thus, motorized vehicles are removed from the traffic at the rates of 2.5%, 5%, 7.5%, and 10% without micromobility (MM), and MM vehicles are included in the system in proportion to the area (number of passengers) occupied by these vehicles in the traffic. Thus, the performance of the intersection is analyzed for these five different cases in terms of three performance indicators, including average vehicle speed, queue delay, and vehicle travel times. When the MM ratio at the intersection is low (2.5%-5%), the average vehicle speed increases by up to 8.2%, while the queuing time decreases by 13.5% and the vehicle travel time improves. However, the intersection performance deteriorated when the MM ratio increased above 5%. At 10% MM, queuing delays increased by 35%, average speeds decreased by 14%, and vehicle travel times worsened due to inefficient signal phasing for MM vehicles. This is also because MM vehicles have to wait while crossing between intersection arms due to inappropriate signaling, which prevents the passage of other motor vehicles. This worsens the performance of the intersection as MM vehicles enter the traffic after a certain percentage. All performance indicators show a better trend with the adjustment of the signal duration. After this adjustment, queuing delays for 7.5% MM decreased by 21% and travel times improved by 9% compared to the previous signal conditions. However, there is still poor performance, especially at 10% MM in traffic. This situation requires a special signalization study for MM vehicles at intersection crossings. Additionally, this study guides policymakers and transportation management decision-makers in their non-motorized transportation planning and future decision-making processes by demonstrating the effects of MM vehicles on intersection performance. This study can be further developed through a priority signal optimization study for MM users. Furthermore, the impact of MM vehicles on traffic safety and MM user behavior under different traffic conditions can be investigated. Such studies will contribute to making urban transportation more efficient.

Article Information Form

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Authors' Contrtibution

The author confirms sole responsibility for the study.

The Declaration of Conflict of Interest/Common Interest

No conflict of interest or common interest has been declared by the authors.

The Declaration of Ethics Committee Approval

This study does not require ethics committee permission or any special permission.

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Appendix

Table A1: Vehicle occupancy rates determined according to the city of Istanbul

	Region								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Car	1.5	1.5	1.6	1.5	1.5	1.5	1.5	1.7	1.6
Public Transport	17.8	15.4	22.1	42.4	44.5	21.1	22.6	30.4	28
Service car	14.1	12.3	8.5	9.4	11.7	9.6	11.9	10.7	10.3
Commercial vehicle	2	1.7	1.6	1.7	1.4	1.6	1.9	2.2	2
Intercity buses	39.9	34.4	26.3	34.7	28.7	35.3	60.7	50.7	38.5
Motorcycle	2.1	2.5	1.9	1.8	1.2	1.2	2.3	2.3	2.1
Total	3.5	4.4	3.1	3.4	4.3	3.4	4.5	4.5	3.3

Table A2: Traffic routes

Point	**Number of vehicle**	**Traffic flow**	**Route**
1	151	17%	YY → İzmir
	335	38%	YY → Hospital
	398	45%	YY → Özlüce
3	125	13%	Özlüce → YY
	673	70%	Özlüce → İzmir
	163	17%	Özlüce → Hospital
5	281	19%	Hospital → YY
	666	36%	Hospital → Özlüce
	532	45%	Hospital → İzmir
7	355	18%	İzmir → Hospital
	857	58%	İzmir → Özlüce
	266	24%	İzmir → YY

(a)

No	Signal group	Signal sequence	0 10 20 30 40 50 60 70 80 90 98	🟥	🟩	🟥	🟩	🟥	▨
1	Signal group 1	R	47	95	47			1	3
2	Signal group 2	R	47	95	47			1	3
3	Signal group 3	R	51 91	50	91			1	3
4	Signal group 4	R	51 91	50	91			1	3
5	Signal group 5	R	50	95	50			1	3
6	Signal group 6	R	50	95	50			1	3
7	Signal group 7	R	49 91	48	91			1	3
8	Signal group 8	R	49 91	48	91			1	3
9	Signal group 9	Permanent							
10	Signal group 10	R	75	95	75			1	3
11	Signal group 11	R	31 49	48	31			1	3
12	Signal group 12	R	31 49	48	31			1	3
13	Signal group 13	Red-Gre	50 96	50	96				
14	Signal group 14	Permanent							
15	Signal group 15	Red-Gre	49 94	94	49				
16	Signal group 16	Red-Gre	49 94	94	49				
17	Signal group 17	Permanent							
18	Signal group 18	Red-Gre	78 95	78	95				
19	Signal group 19	Red-Gre	35 48	35	48				
20	Signal group 20	Red-Gre	35 48	35	48				

(b)

No	Signal group	Signal sequence	0 10 20 30 40 50 60 70 80 90 98	🟥	🟩	🟥	🟩	🟥	▨
1	Signal group 1	R	43	95	43			1	3
2	Signal group 2	R	43	95	43			1	3
3	Signal group 3	R	57 87	56	87			1	3
4	Signal group 4	R	57 87	56	87			1	3
5	Signal group 5	R	50	95	50			1	3
6	Signal group 6	R	50	95	50			1	3
7	Signal group 7	R	49 91	48	91			1	3
8	Signal group 8	R	49 91	48	91			1	3
9	Signal group 9	Permanent							
10	Signal group 10	R	75	95	75			1	3
11	Signal group 11	R	31 49	48	31			1	3
12	Signal group 12	R	31 49	48	31			1	3
13	Signal group 13	Red-Gre	50 90	50	90				
14	Signal group 14	Permanent							
15	Signal group 15	Red-Gre	49 94	94	49				
16	Signal group 16	Red-Gre	49 94	94	49				
17	Signal group 17	Permanent							
18	Signal group 18	Red-Gre	81 93	81	93				
19	Signal group 19	Red-Gre	36 44	36	44				
20	Signal group 20	Red-Gre	36 44	36	44				

Figure A1: Signal time tables; (a): current situation, (b): adjusted signal table