Evaluation of the Effects of Autonomous Public Transportation Vehicles on Traffic Conditions

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Abstract

Since the first automobile, there have been many inventions and innovations relevant to the automobiles such as hybrid electric vehicles, emergency break assist, adaptive cruise control and lane guard system. Up until now, all these developments have aided the driver in the vehicle. But recently, an idea of driverless cars, also called as autonomous vehicles, is introduced to change the whole structure of cities and transportation infrastructures. An autonomous vehicle is a car that can move from one point to another without a driver intervention such as steering, breaking and so on. It is a technology that is already in development. With an increase in percentage of autonomous vehicles, an increase in safety on roads and a decrease of road accidents and congestion are expected. By converting the public transportation vehicles into driverless vehicles, the overall system is expected to operate in a much efficient, accessible and safer manner. In this study, 60 scenarios will be compared where each of these scenarios will have different demand levels and percentages of autonomous vehicles in the network. Introduction of a bus lane improved the travel time of the buses by 34.95% whereas converting the buses into autonomous buses provided a decrease for the travel time by 1.3% when the traffic demands are at maximum level and all private vehicles are autonomous. When both are introduced at the same time, the average travel time of buses decrease by 35.58%. The findings of this study can be a guideline for policy makers and city planners by showing them what element of traffic to prioritize.

Keywords: *Public transportation, autonomous vehicles, bus lanes.*

1 Introduction

The invention of automobiles has a huge impact on the way of life and the society of people. Developments in technology and innovative progresses introduced different automobile concepts, the latest one being the autonomous automobile progression. The autonomous vehicles are able to travel without the intervention of a driver for important tasks such as detecting the road and their surroundings. Technologies like radar, LIDAR, GPS, odometer and computer view combined with special techniques all support the automobile itself for doing the tasks that a normal driver would normally do. There are 5 levels of automation determined by the Society of Automotive Engineers (SAE, 2014) and today's vehicles in traffic are designed as partially autonomous. The benefits of the autonomous vehicles as the level of automation increase varies in different aspects.

An autonomous vehicle can detect dangerous situations and act accordingly in traffic much faster than regular human drivers. Due to this fact an increase in the capacity of roads and intersections and a decrease in the number of road accidents, reduced travel time is expected as well as fuel and energy efficiency (Dresner and Stone, 2008). The significant relationship between road accidents and traffic congestion signifies that with the reduced number of accidents, the traffic congestion will also decrease (Gökaşar, 2016). The autonomous vehicles can also provide mobility for the non-drivers, elderly and people with physical disabilities (Alkan, 2017). With the convenience provided by this new technology the overall productivity is also expected to be increased. The end result is to have economic benefits and a positive impact on the environment. However, there are also risks for this new technology. The fact that this technology is not expected to dominate the global traffic any time soon, means that the human driven vehicles and autonomous vehicles have to co-exist. According to different studies, Level 4 or 5 autonomous vehicles will be used in a restricting manner in 2020s and their wide usage will not be before 2040s (Hedlund, 2017). Also, for this newer technology, the existing infrastructure must be future proofed by having lanes on roads for connected vehicles. Operating a vehicle on public roads can be very complex due to the high frequency of interactions with other objects such as vehicles, pedestrians, cyclists, animals and potholes. As the complexity of producing a system as challenging as this, high costs and system failures are to be expected. Also, when the main causes of traffic congestion are considered, the high number of active vehicles in traffic is an important cause. By providing an opportunity for the non-drivers to join the traffic, new vehicles are expected to be added to the current traffic. The increased number of vehicles can harm the traffic conditions even further with increased travel times and traffic congestion. The convenient travelling can also indicate an increase for the number of travel per passenger, causing a significant demand increase in the traffic. This situation can be a significant obstacle for the potential advantages that will be provided with the increased common usage of autonomous vehicles. To avoid this, one must consider ways to decrease the number of vehicles.

Public transportation, ride-sharing, car-sharing and similar systems are all very potentially beneficial systems to decrease the number of vehicles in traffic. (Hasabe et. al., 2017) proposed a system, where autonomous vehicles are used for traffic management for last-mile public transportation systems. Shared autonomous rides, self-driving vans that are taking the passengers to or near destinations can offer lowest costs for its users, especially when compared to the alternative which is to buy their own personal autonomous vehicles (Giesel and Nobis, 2016). Providing incentives such as reduced parking costs and public transportation tickets will maximize the efficiency and promotion of both car sharing and public transportation systems (Cervero and Tsai, 2004). Even though these systems offer lesser convenience, comfort and speed, especially in sprawled areas, the advantages outweigh the inconveniences. Furthermore, providing special infrastructure that will improve the efficiency of public transportation systems, such as bus lanes for public buses, is very crucial.

Exclusive bus lanes (XBL) are lanes that are dedicated only to the public buses. With these lanes it is aimed that the public transportation vehicles have priority in the traffic and the level of interaction between the public transportation vehicles and the rest of the traffic is minimized. XBLs have a positive impact on the public buses by reducing the travel times of public transportation vehicles (Yang and Wang, 2009). Surveys made in city of Kunming show that the bus lane is outstanding in terms of environmental protection and passenger transport efficiency (Wei and Chong, 2002). However, presence of a XBL also causes a reduction in capacity of the road. It is important that the benefits provided by XBLs are maximized while the deterioration to the rest of the traffic is minimized.

In this study, by changing, the traffic demand levels in the network, the percentage of private and public vehicle's being autonomous and introducing a bus lane for the constructed network, the traffic conditions will be inspected. The average travel time of the vehicles for their assigned origin and destination points and the mean speed of the vehicles will be the considered. There will be, in total, 60 scenarios to be inspected. The end results are expected to provide an insight for which parameters, the traffic conditions improve the most. Also by making comparisons, it will be possible to observe whether autonomous public transportation vehicles or bus lanes improves the transit system by minimizing the deterioration to the rest of the traffic.

2 Methodology

For the analysis Turgut Ozal Avenue between Aksaray and Topkapı intersections is modelled in the PARAMICS traffic simulation software. The length of the inspected road network, which has many intersections, is 2.5 km and has three lanes. For the calibration of the model, the vehicles have been counted by utilizing cameras. In total 22 detectors are installed on this network model, which are separated into 5 groups (Figure 1). The detectors are placed such that the important intersections are covered. These detectors gather the occupancy, speed and headway. The simulation takes measurements for 75 minutes. The first 15 minutes are considered as a warm up period so the average travel time and mean speed data for that period of time is discarded while taking measurements. The final values are considered for 1-hour period of time.

The general behavior of the PARAMICS model are calibrated by adjusting the average time headway between vehicles and drivers' reaction time (PARAMICS Handbook, 2015). The average time between vehicles is the average amount of time between a vehicle in the system and the vehicle following it. The average drive response time is measured in the time interval between the change of the speed of the vehicle ahead and the response of the following vehicle. Unit for both parameters are in seconds (Ma and Yang, 2007). For both parameters the lower boundary is 0.5 seconds. The upper boundary is 5 seconds for the average time headway between vehicles and 2.2 seconds for drivers' reaction time (May, 1990). The mean target time between vehicles and mean drive response time were calibrated by trial and error as 0.7 and 0.9 seconds respectively.

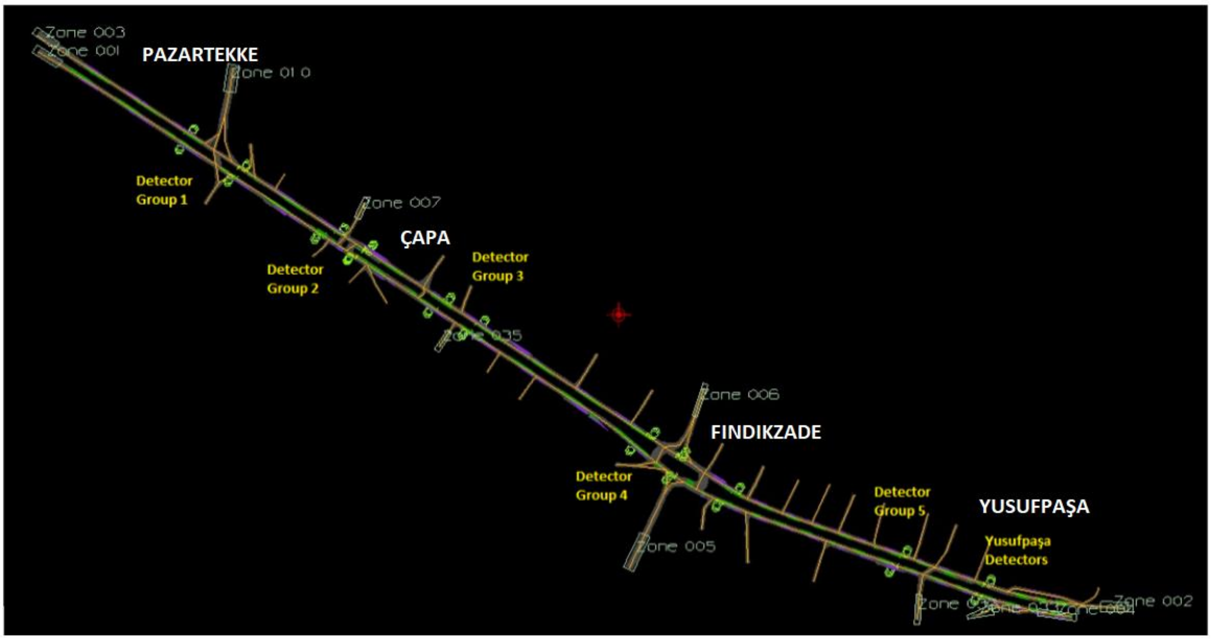

Figure 1. Locations of the detector groups and the traffic generating zones on the road network built in PARAMICS software.

The performance table (Table 1) is generated, where the observed count values were compared with the values obtained through the simulated model. The difference between the correct values and the simulated results (sensor) was taken as an error and these values were divided by the correct values and the error rate was found. The average of these values was evaluated as the error rate of the simulation system (Table 1).

$$Error\ rate = \sum_{i}^{n} \frac{Sensor_i - Count_i}{Count_i} \times \frac{100}{n} \quad (1)$$

Table 1. The test scenarios for the given road network.

	Entrance From Topkapı (%)	**Exit From Topkapı (%)**	**Southward Çapa (%)**	**Northward Çapa (%)**	**Exit From Yusufpaşa (%)**	**Entrance From Yusufpaşa (%)**
1st Time Interval	0.92	8.22	1.90%	10.74	0.00	1.13
2nd Time Interval	10.26	10.24	5.75%	9.43	12.32	4.80
3rd Time Interval	5.35	2.61	3.39%	0.00	7.83	6.75
4th Time Interval	0.31	2.74	2.33%	1.07	1.92	11.42
Sensor average (%)	**4.21**	**5.95**	**3.34**	**5.31**	**5.52**	**6.03**
Total Average (%)			**5.06**			

In this study, for the built model of the road network, the impact of the autonomous vehicles and availability of a bus lane will be tested within the scope of;

1. Three different traffic demand levels in the network (75%, 90% and 100% of the total traffic demand),

2. Four different percentage levels of autonomous vehicles in the network (0%, 25%, 50%, 75% and 100% of the private vehicles are autonomous),
3. The availability of a bus lane,
4. The public buses in the network being completely autonomous in 60 scenarios.

The following scenarios given in the table below is repeated for three different levels of traffic demands starting from the lowest demand (75% of the total traffic demand) to the highest demand (100% of the total traffic demand) (Table 2). With the combinations of these given parameters, the aim is to observe the impact of autonomous public busses and private vehicles and the presence of a bus lane on the rest of the traffic. Average travel times and the mean speeds of private vehicles and public transportation vehicles in the network will be inspected.

Table 2. The test scenarios for the given road network.

Scenario	Availability of A Bus Lane	% of Autonomous Private Vehicles in Traffic	% of Public Bus Fleet Being Autonomous1
	Not available (B0)	0 (A000)	0
	Not available (B0)	25 (A025)	0
1 to 15	Not available (B0)	50 (A050)	0
	Not available (B0)	75 (A075)	0
	Not available (B0)	100 (A100)	0
	Available (B1)	0 (A000)	0
	Available (B1)	25 (A025)	0
16 to 30	Available (B1)	50 (A050)	0
	Available (B1)	75 (A075)	0
	Available (B1)	100 (A100)	0
	Not available (B0)	0 (A000)	100
	Not available (B0)	25 (A025)	100
31 to 45	Not available (B0)	50 (A050)	100
	Not available (B0)	75 (A075)	100
	Not available (B0)	100 (A100)	100
	Available (B1)	0 (A000)	100
	Available (B1)	25 (A025)	100
46 to 60	Available (B1)	50 (A050)	100
	Available (B1)	75 (A075)	100
	Available (B1)	100 (A100)	100

3 Simulation Results

After the simulation is completed, the outputs which are average travel time and mean speed, are collected for private vehicles, public transportation vehicles and for all of the vehicles in the network (Table 3). The comparisons are made for each demand level and taking the base case where there is no autonomous private vehicle in the network. From Table 2, it can be seen that the increase of autonomous vehicles in traffic, improves the traffic conditions in terms of reduced travel times and increased mean speed values. However, the introduction of a bus lane while improving the condition of the buses, causes increased travel times and decreased mean speeds for the private vehicles.

Table 3. Change in value in terms of percentage for the tested scenarios.

Scenario Index	% Change In Travel Time For Private Vehicles	% Change In Mean Speed For Private Vehicles	% Change In Travel Time For Public Buses	% Change In Mean Speed For Public Buses	% Change In Travel Time For All Vehicles	% Change In Mean Speed For All Vehicles
1	-	-	-	-	-	-
2	-6.69	8.69	1.57	-3.45	-6.50	8.74
3	-10.42	15.11	-2.11	0.55	-10.14	14.77
4	-9.77	15.11	0.20	-1.33	-9.45	14.76
5	-23.01	38.54	-8.10	6.85	-22.47	37.90
6	-	-	-	-	-	-

7	-1.45	0.54	-0.18	1.87	-1.49	2.54
8	-5.64	8.69	-1.29	2.00	-5.65	8.38
9	-12.93	19.63	-1.08	0.37	-12.79	19.31
10	-15.18	28.70	-0.48	-0.68	-14.87	27.64
11	-	-	-	-	-	-
12	-1.80	5.69	0.86	0.83	-1.78	5.45
13	-4.08	9.45	0.57	-0.95	-3.96	9.06
14	-6.35	9.27	3.98	-4.46	-6.10	8.89
15	-9.92	16.89	5.09	-4.96	-9.55	16.20
16	-	-	-	-	-	-
17	-6.16	4.14	0.32	-0.45	-6.07	3.90
18	-5.88	4.11	-0.53	0.57	-5.87	5.69
19	-4.32	-0.07	0.62	-0.93	-4.27	0.34
20	-9.26	8.35	-0.07	-0.09	-9.18	8.27
21	-	-	-	-	-	-
22	-1.07	-4.24	1.85	-1.50	-1.01	-3.95
23	-5.27	8.25	0.24	-0.28	-5.24	5.50
24	-7.64	9.33	0.49	0.09	-7.58	6.51
25	-7.49	9.39	1.60	-0.94	-7.45	7.02
26	-	-	-	-	-	-
27	-0.36	1.48	-0.20	0.18	-0.40	1.42
28	-2.79	2.06	0.06	-0.19	-2.79	4.50
29	-3.03	6.45	-0.29	0.18	-3.07	6.12
30	-5.29	8.02	-0.16	0.18	-5.32	7.62
31	-	-	-	-	-	-
32	-0.63	1.72	5.37	-4.24	-0.45	0.49
33	-4.87	3.21	-0.34	1.13	-4.71	3.11
34	-10.53	14.16	0.90	-1.17	-10.12	13.92
35	-11.86	15.01	0.12	-0.35	-11.41	14.74
36	-	-	-	-	-	-
37	-4.54	9.70	-0.93	2.13	-4.62	9.36
38	-8.41	14.55	0.59	-2.46	-8.14	14.43
39	-10.74	16.71	-0.04	-2.83	-10.43	16.10
40	-11.41	16.32	-0.50	-2.21	-11.06	15.73
41	-	-	-	-	-	-
42	-1.70	6.78	0.36	-0.44	-1.54	6.48
43	-3.63	9.14	-2.20	1.34	-3.50	8.75
44	-6.82	12.72	0.65	0.53	-6.69	12.18
45	-11.31	16.75	1.72	-4.57	-10.95	16.04
46	-	-	-	-	-	-
47	0.28	-1.86	-0.24	-0.09	0.21	-1.76
48	-0.38	1.56	0.23	-0.64	-0.41	1.47
49	-5.52	7.66	-0.54	0.10	-5.49	7.22
50	-7.23	12.44	1.09	-1.65	-7.20	11.72
51	-	-	-	-	-	-
52	-2.08	4.66	0.96	-1.39	-2.10	6.73
53	-2.78	5.03	0.40	-0.19	-2.80	7.08
54	-7.48	12.13	-0.64	1.10	-7.48	11.53
55	-8.27	11.84	-0.06	0.45	-8.25	13.56
56	-	-	-	-	-	-
57	-1.00	-1.55	-0.28	0.28	-0.98	-1.48
58	-1.55	-1.47	0.20	-0.47	-1.57	-1.41
59	-3.04	2.11	1.17	-1.21	-3.05	4.48
60	-3.90	3.52	0.00	-0.55	-3.94	3.34

Looking at the graphics for public buses where their average travel time (Figure 2) and mean speeds (Figure 3) are shown, it is immediately noticed that there is a significant improvement of their operating conditions with decreased average travel times and increased mean speeds, when there is a bus lane available in the network. However, when there is a bus lane that is available, the buses being autonomous does not further improve the conditions of the public transportation system significantly. When there is no bus lane in the network, the improved conditions due to private vehicles being autonomous is only considerable when the overall traffic demand for the network is at its lowest. For the highest 2 traffic demands, converting neither private vehicles nor public buses into autonomous vehicles does not seem to be improving the conditions of the buses. Introduction of a bus lane improved the travel time of the buses by 34.95% whereas converting the buses into autonomous buses provided a decrease for the travel time by 1.3% when the traffic demands are at maximum level and all private vehicles are autonomous. When both bus lane and autonomous buses are introduced to the network at the same time, the average travel time of buses decrease by 35.58% for the same conditions as before. From this observation it can be concluded that introduction of a bus lane is much more feasible than converting the entire traffic into autonomous machines.

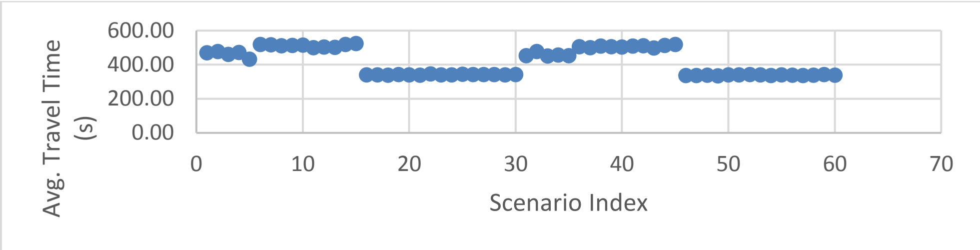

Figure 2. Average travel times of the public buses.

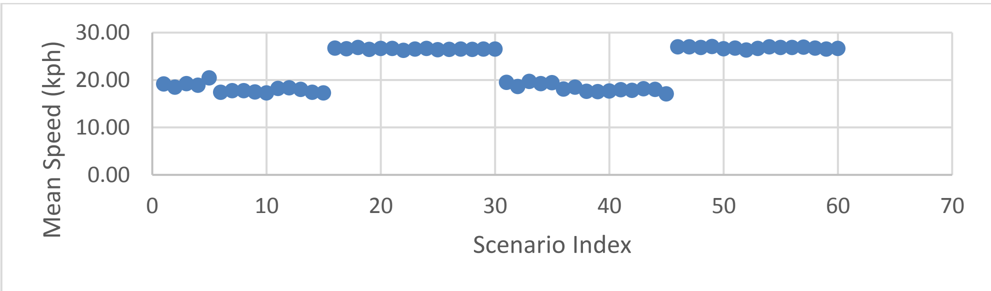

Figure 3. Mean speeds of the public buses.

For the average travel time (Figure 4) and mean speed (Figure 5) of the private vehicles, first thing to notice is the increased percentage of autonomous vehicles for all traffic demand levels improve the travel time and mean speed values for private vehicles. However, the amount of improvement decreases as the traffic demand level increases. A decrease of average travel time by 23.01% is obtained when all private vehicles are converted into autonomous vehicles, for the lowest level of traffic demand with no bus lane and autonomous buses in the network. Worst conditions for private vehicles are obtained when there is a bus lane on the network and there are no autonomous private vehicles at all. The public transportation vehicles being autonomous does not seem to be affecting the conditions of the private vehicles significantly, even more so in some cases it worsens the conditions but not in a considerable amount. When there is a bus lane, the traffic demand is at its maximum level and all private vehicles are autonomous, converting the buses into autonomous buses causes an increase of the average travel time amount of the private vehicles by 1.74%.

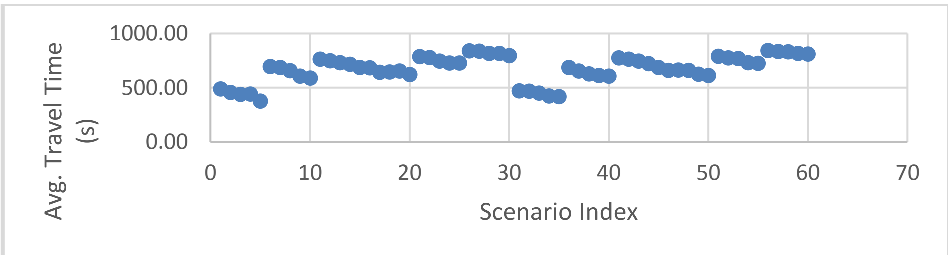

Figure 4. Average travel time of the private vehicles.

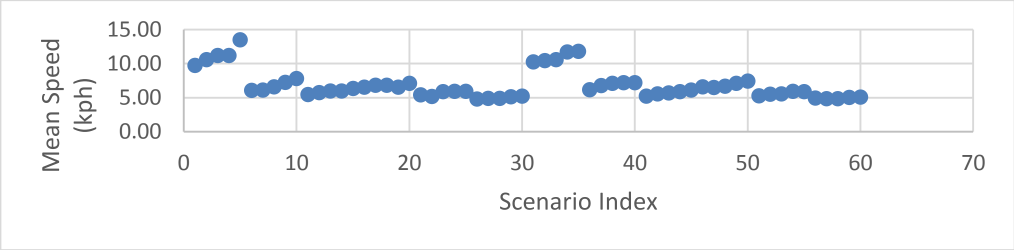

Figure 5. Mean speeds of the private vehicles.

When all of the vehicles in traffic (both private vehicles and public buses) some clear observations can be made. As the percentage of autonomous private vehicles increase, the conditions of the traffic improve. The most benefit is gained by a decrease of average travel times by 22.47% (Figure 6) and an increase of mean speed by 37.90% (Figure 7) at minimum traffic demand level where there is no bus lane and autonomous public buses and all vehicles are autonomous. The gained benefit decreases as the demand level increases and when a bus lane is introduced it decreases even further. For the case where the level of traffic demand is at maximum and all private vehicles are autonomous, the introduction of a bus lane and converting all buses into driverless buses causes an increase for the overall traffic's average travel time by 17.23% and a decrease for the mean speed by 18.66%.

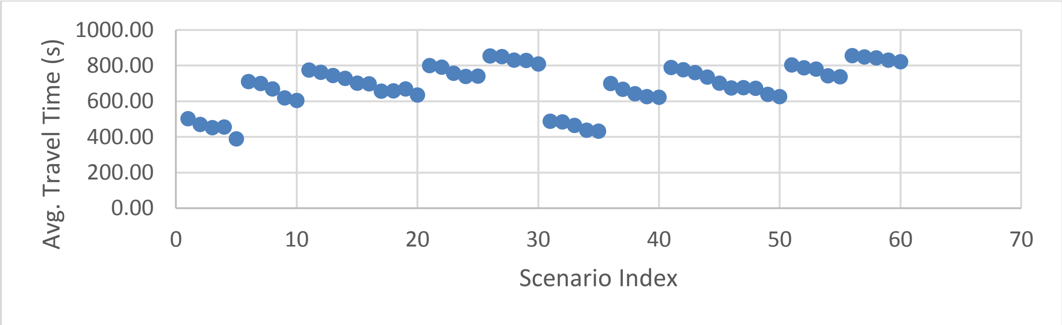

Figure 6. Average travel times of all vehicles in the network.

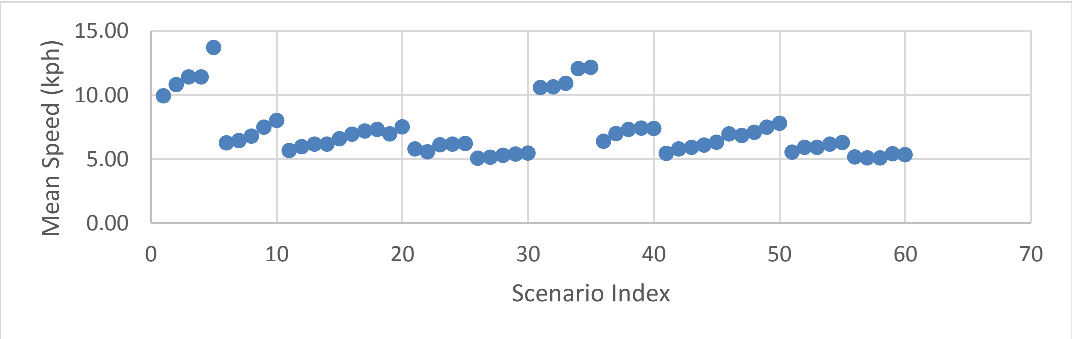

Figure 7. Mean speeds of all vehicles in the network.

4 Conclusion

In this study, the impact of autonomous private and public transportation vehicles on the overall traffic conditions are examined. The results show that the introduction of a bus lane benefits the conditions of the public buses the most but harms the rest of the traffic in a significant manner. Converting the entire fleet of public buses into autonomous vehicles also does not improve the conditions of public buses that much and introducing both bus lane and autonomous buses does not improve the performance of buses a considerable amount. This is an important finding due to the fact that converting the entire bus fleet into autonomous vehicles would be a very expensive operation and introducing a bus lane on a road is much easier and more feasible. An insight as such as this one can provide crucial information for the policy makers especially if there is a necessity for a very feasible solution. The accessibility and safety of the public buses however, is still an issue to be solved. Converting public buses into autonomous machines can be answer to this issue.

The increased levels of autonomous vehicles also benefit the traffic condition for each traffic demand level. However, as the traffic demand increases these benefits starts to diminish. The traffic demand can be expected to increase even further until the autonomous vehicles can no longer improve the traffic conditions, due to reasons such as the convenience of autonomous vehicles and adding the non-drivers into the traffic causing an increase of number of vehicles in the traffic. The result is a strong indication for the fact that, to decrease the congestion and improve the traffic conditions, the number of vehicles in the traffic must be decreased and the public transportation systems must be promoted much more. The focus of policy makers and city planners must shift towards decreasing the negative effect of bus lanes on the rest of the traffic and the number of private vehicles in traffic by promoting public transportation. Finally, the end results can be summarized as follows:

- Introduction of a bus lane improved the travel time of the buses by 34.95% whereas converting the buses into autonomous buses provided a decrease for the travel time by 1.3% when the traffic demands are at maximum level and all private vehicles are autonomous.
- When both bus lane and autonomous buses are introduced to the network at the same time, the average travel time of buses decrease by 35.58% for the same conditions as before. From this observation it can be concluded that introduction of a bus lane is much more feasible than converting the entire traffic into autonomous machines.
- When there is no bus lane in the network, the improved conditions due to private vehicles being autonomous is only considerable when the overall traffic demand for the network is at its lowest.
- Policy makers can utilize these findings for improving the public transportation of a city in a much feasible and simpler way.

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