

## Research Article

# The Impact of Automated Vehicles on Traffic Flow and Road Capacity on Urban Road Networks

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Automated vehicles (AVs) are believed to have great potential to improve the traffic capacity and efficiency of the current transport systems. Despite positive findings of the impact of AVs on traffic flow and potential road capacity increase for highways, few studies have been performed regarding the impact of AVs on urban roads. Moreover, studies considering traffic volume increase with a mixture of AVs and human-driven vehicles (HDVs) have rarely been conducted. Therefore, this study investigated the impact of gradual increments of AV penetration and traffic volume on urban roads. The study adopted a microsimulation approach using VISSIM with a Wiedmann 74 model for car-following behavior. Parameters for AVs were set at the SAE level 4 of automation. A real road network was chosen for the simulation having 13 intersections in a total distance of 4.5 km. The road network had various numbers of lanes from a single lane to five lanes in one direction. The network consists of a main arterial road and a parallel road serving nearby commercial and residential blocks. In total, 36 scenarios were investigated by a combination of AV penetrations and an increase in traffic volumes. The study found that, as AV penetration increased, traffic flow also improved, with a reduction of the average delay time of up to 31%. Also, as expected, links with three or four lanes had a more significant impact on the delay. In terms of road capacity increase, when the penetration of AVs was saturated at 100%, the road network could accommodate 40% more traffic.

## 1. Introduction

Automated vehicles (AVs) are almost commercially ready for the public in many countries. Boston consulting group [1] predicts that manufacturers will introduce AVs into the car market by 2025 and that by 2035 they will have a 10% share of the market. Litman [2] estimates that 80~100% of cars on the roads by 2045 will be AVs, while Bansal and Kockelman [3] predict that the market share of AVs will be between 24% and 87%. Regardless of the detailed figures in the predictions, it is certain that AVs will fill up the roads within 20 years.

In terms of mobility, AVs will bring a fundamental revolution to our life. People will not need to drive and therefore will be free from the stress of driving. They can enjoy their time pursuing other activities in their car.

Transport planners and policymakers believe that AVs have great potential for resolving many traffic-related problems, e.g., traffic congestion. The traditional solution to mitigate traffic congestion is capacity expansion. However, building more roads is not a feasible solution, as there is little space available for roads in urban areas [4].

AVs can drive accurately on roads and with better sensing ability than humans. Specifically, they require a much smaller gap, or shorter headway, than human-driven vehicles (HDVs), since they have more information about the surrounding driving environment and a slower reaction time delay [5–8]. Vehicle-to-vehicle (V2V) communication will allow vehicles to form platoons [6, 9]. These technological advances will be able to increase traffic flow efficiency and road capacity.

However, there are still gaps in the estimation of improvement by AVs depending on road categories and the relative proportion of AVs and HDVs. According to previous studies, AVs can improve traffic flow [10–12], consequently, allowing increased road capacity [13, 14] of up to 50% in uninterrupted flow [5, 6, 8]. However, another study reports that the improvement will not be significant (or could even worsen) until a penetration rate of 40% is achieved [15]. Most of the previous studies report the impact of AVs on highways, but the impact on urban roads is rarely reported. The final objective of AV technology is to allow AVs to run on all roads, regardless of road environment or category. While highways are relatively easy for AVs, vehicle movements on urban roads are restricted by the environment, such as traffic signals at intersections, so the impact of AVs will be different on urban roads. Therefore, studies are necessary to investigate the impact of AVs on traffic flow on urban road networks.

This study aims to investigate and predict the impact of AVs on traffic flow in three aspects. First, the study focuses on urban roads, with their characteristic interrupting traffic flow. Second, it will investigate the impact of penetration rate changes of the AVs (a mixed condition of AVs and HDVs). Third, it will investigate the impact of AVs on road capacity—how much more traffic the current road network can accommodate by introducing AVs. In addition, the study focuses on AVs at level 4 of vehicle automation by the Society of Automotive Engineers (SAEs) [16]. The SAE defines level 4 as embodying a high degree of automation. In level 4, the cars do not require human intervention in most circumstances.

## 2. Literature Review

The following sections summarize the previous studies that investigated the impact of AVs and their methods.

Several studies reported that AVs improve traffic flow and increase road capacity. These improvements would get larger as the AV penetration rate increased [7, 17–20]. Talebpour et al. [18], in a study for a four-lane highway using simulation modeling, found that traffic flow improved for AV penetration above 30%. Similarly, Van Arem et al. [19] noted that the impact of AVs was noticeable when the penetration rate exceeded 40%. They also reported that road capacity was increased when the penetration rate exceeded 50%. Likewise, Jones and Philips [20] reported that vehicles with Cooperative ACC (CACC) would improve traffic flow when the penetration rate exceeded 40%.

In contrast, Calvert et al. [21], in the study about the impact of Adaptive Cruise Control (ACC), simulated a motorway of 19 km with three lanes. They found that an improvement in traffic flow was only identified at a penetration rate above 70%. Moreover, there was a small drop in road capacity up to a penetration rate of 80%. A study by Tientrakool et al. [22] found that road capacity significantly improved after the vehicle penetration rate with CACC exceeded 85%.

There are a few studies that deal with urban roads. Lu et al. [17] focused on the impact of AVs on urban road capacity using a microsimulation model. They found a 16% increase in road capacity with an artificial grid network at an

AV penetration rate of 100% while a 23.8% increase for the real road network in Budapest, Hungary. Yongseok Ko et al. [7] investigated the impact of AVs on travel time savings at the macrolevel. They reported that AVs reduced travel time from a penetration rate of 20% in the Seoul Metropolitan area. On the other side, the reduction in travel time started from a penetration rate of 60% in an interregional network. They concluded that AVs were more effective on congested roads. However, the study by Friedrich [13] reported a contrast from the findings of Ko et al. They concluded that, at an AV penetration rate of 100%, road capacity increased by 40% in urban areas compared to 80% on highways.

There are also a few studies regarding the impact of AVs at intersections. Zohdy and Rakha [23] and Bichiou and Rakha [24] investigated the impact of Cooperative Automated Vehicles (CAVs) on a signalized intersection and a roundabout. They focused on the cooperative and connected function of AVs and modeled a single intersection. They found that there was a 70~80% reduction in delay.

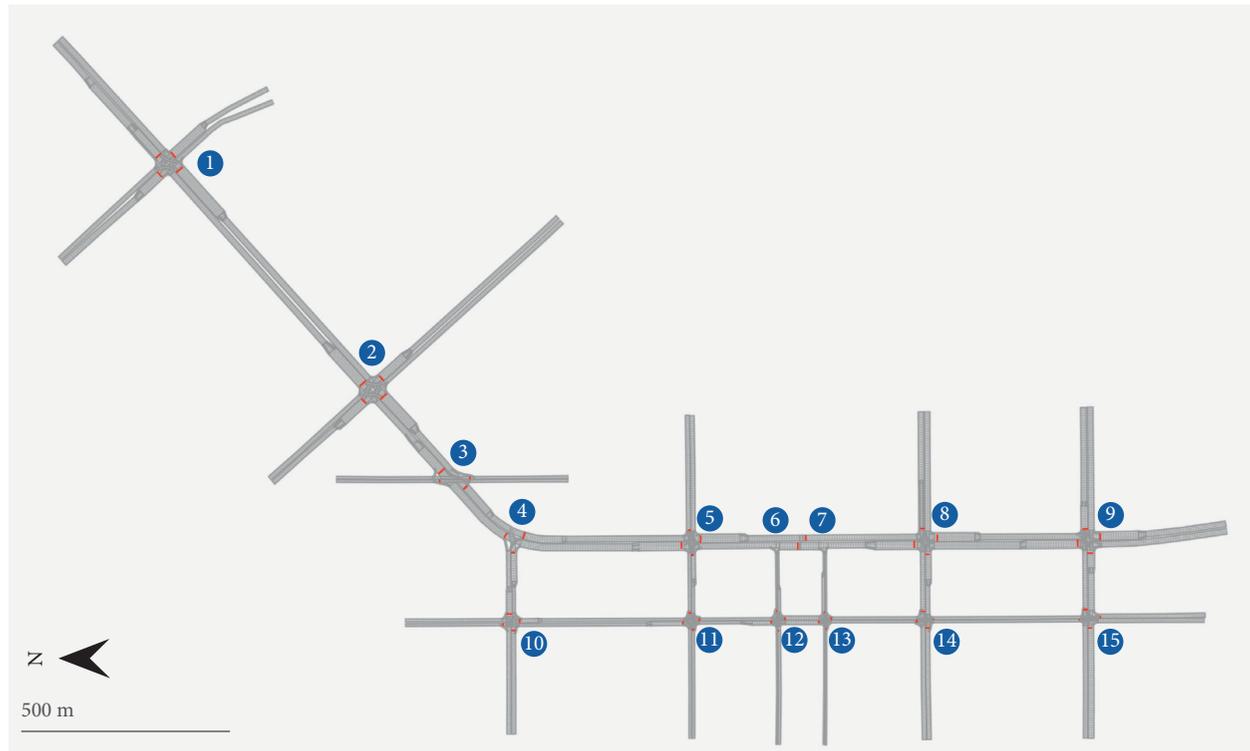
Meyer et al. [25] and Park et al. [26] noted the possibility of increased car use demand and consequent lack of road capacity. They argued that travel demand by kids, the elderly, and the handicapped would rapidly increase, as well as moving from public transport use to car use since there would be no burden to drive themselves.

In terms of methods for AV-related studies, transport simulation modeling is a significant approach to evaluate the impact of AVs [27]. The majority of the previous studies adopted a simulation modeling approach based on traffic [7, 13, 17–22, 24, 25]. Some of them were studied at the macroscopic level [7, 13, 25], while many of them were investigated at the microscopic level [17–22, 24]. However, with low penetration of AVs, there are no available definitive characteristics of traffic made up mainly of AVs. As part of the mainstream, AVs are still being tested, so a microscopic modeling approach is useful as it reflects detailed and different behaviors between AVs and HDVs in a model [8, 27–33].

## 3. Methods

The study adopted a microsimulation approach, since our primary concern is to assess the impact of AVs based on their behavior, and no AVs currently run on roads, except for a few test cars. The study also took a real-world road network in South Korea. An artificial road network can be helpful to identify the impact of AVs; however, this will have limitations regarding reflecting real road situations.

**3.1. Study Area and Data Collection.** A road network was selected to reflect the numbers of lanes and traffic flows of newly developed cities of Korea (Figure 1). The central area of the Bundang district in Seongnam city was selected. The area has mixed land uses of mass residential blocks with commercial and business blocks nearby. The road network is 4.5 km in total length with 13 intersections and from one lane to five lanes in one direction. In Figure 1, No. 6 and No. 7 are T-intersections with median barriers. So, the left-turn movement from all intersection approaches is prohibited.



Numbers of Lane (Both directions)

- 8 Lanes +
- 6 Lanes
- 4 Lanes
- 2 Lanes
- Stop line

FIGURE 1: Layout of the road network.

The selected site has a main arterial road (from No. 1 to No. 9) connecting northern and southern areas of Seongnam city, and a road section in parallel with the arterial road (from No. 10 to No. 15) serves commercial and residential blocks. Moreover, the arterial road section is the main commuting route for Seoul. All the roads have well-designed pedestrian paths but there are no bike lanes on the roads. Therefore, bike traffic was not considered as only 1.8% of transport demand is served by bicycles [34].

In terms of the composition of lanes of road links, the arterial road section from No. 1 to No. 9 has four or five lanes in each direction (eight or more lanes in both directions). Only one link starting from No. 2 to No. 3 has five lanes. Links from No. 8 to No. 14 and from No. 9 to No. 15 have three lanes in each direction. A link from No. 10 to No. 4 also has three lanes. Links from No. 6 to No. 12 and from No. 7 to No. 13 have a single lane in each direction. All the remains have two lanes in each direction (mainly a road from No. 10 to No. 15).

Data collection was conducted to reflect the traffic conditions found in a real road network. It was carried out for three weekdays in July 2020. The team recorded traffic flows using video cameras for two hours from 7 am to 9 am at each intersection of the network. The volume of traffic

passing the intersections in each direction, queue lengths, and traffic signal changes were recorded. The traffic counts were used as input traffic data for modeling and the calibration and validation of modeling HDVs, while the traffic signal data were used to check the traffic signal data provided by the city council.

The arterial road section had 1,904 vehicles per hour on average in the northbound direction and 1,414 vehicles per hour in the southbound direction, while the parallel section had 202 vehicles per hour in the northbound direction and 216 vehicles per hour in the southbound direction. According to the arterial level of service for urban street class III by Highway Capacity Manual [35], links of the arterial road had a level of service that ranged from B to D while links of the parallel road had a level of service of D or F. The traffic signal cycles ranged between 120 s and 180 s.

**3.2. Simulation Environment.** As discussed in the Literature Review section, microsimulation traffic modeling is the main approach for AVs-related studies, especially focusing on traffic performance [32, 33]. VISSIM provides two car-following models: Wiedemann 74 and Wiedemann 99. The 74 model is suitable for urban roads, while the 99 model is

better for motorway traffic [36]. As our interest is on the impact of AVs on urban roads, the 74 model was deployed.

VISSIM allows users to set parameters for behaviors of car-following, lane changing, and drivers' characteristics. Various parameters were modified to model the movements of AVs. Default values of the parameters for AVs in VISSIM are at the SAE level 3 of automation [28]. However, as mentioned in the introduction, this study set AVs at level 4 of SAE and the values of parameters for them were derived from previous studies [28, 30, 37, 38]. The SAE defines level 3 and level 4 as high driving automation. In level 3, human drivers usually do not need to drive, but they have to be able to drive when driving is requested. In level 4, human drivers never need to take over driving.

Table 1 shows the various parameters used. The parameters for car-following and lane change for AVs were set to reflect more aggressive and sensitive behaviors of AVs than humans [38]. Cooperative lane change was also allowed for AVs. In terms of driver characteristics, it was assumed that AVs could communicate with other AVs and more easily obtain information about the traffic situation ahead and behind. The desired speed of AVs was fixed at 50 km/h, but it ranged from 48 to 58 for HDVs. The study assumed the HDV had 10% of driver errors, causing unnecessary conflicts of HDVs on the roads. In the model, platooning features were allowed only for AVs. The parameter values for HDVs used the default values of VISSIM.

**3.3. Scenarios and Run.** The study assumed that the penetration of AVs increases and traffic volumes also increase, due to increased demand for car use. The study considered six different rates including 0%, 20%, 40%, 60%, 80%, and 100% for each.

36 scenarios were developed and run for analysis by a combination of AV penetration rate and traffic volume increase, 6 cases for AV penetration rate and 6 cases for traffic volume increase (Figure 2). The base scenario, with the penetration rate of 0% and traffic volume increase of 0%, represents a current traffic environment with no AVs and no traffic volume increase. As expected, the penetration of 100% represents a fully AV environment and a traffic volume increase of 100% means that traffic volumes double.

Simulation runtime was set at 2 hours, including a warm-up period of 15 minutes before and after the simulation. In addition, all scenarios were run ten times with different seed numbers to obtain reliable outputs [39].

Four network performance indicators (average travel time, average vehicle speed, average delay, and stop frequency at intersections) were used to assess the impact of AVs and the increase in traffic volumes on urban roads.

A set of 4 virtual detectors were installed at the start of each link (Figure 3). The detectors measured vehicle speed and travel time in all directions (forward, left turn, and right turn). Delays were calculated from the measured travel time and free-flow time for links.

**3.4. Calibration.** Calibration was carried out using traffic volumes, collected to accurately represent the field

conditions. The process was only for the base case since the exact behaviors of AVs are still unavailable in many areas.

The calibration was performed with all the parameters for HDVs. The more sensitive parameters were identified and given priority for modification. Minimum headway, safety distance reduction factor, desired speed, and driver errors were the most sensitive.

After every modification, the model was run 10 times. The calculated traffic volumes and field observed traffic volumes were then compared for each intersection of the network. After many repetitions, the final difference was within 15% on average. However, not all the differences in the traffic counts for each direction at the intersections were within 15%. The difference along main corridors was generally within 15%. On the other hand, the minor corridors had much larger differences.

## 4. Results and Discussions

**4.1. Change in Traffic Flow by the Penetration Rates of AVs.** In this section, results from the scenarios only with increased AV penetration rate are presented (no traffic volume increase).

Overall, AVs improved traffic flow over the whole network (Table 2). The reduction of delay time was especially significant. As the penetration rate increased from 0% to 100%, the average travel time and average delay of the network decreased by 17% (from 229.99 s to 189.75 s) and 31% (from 126.65 s to 87.74 s), respectively. The average vehicle speed increased by 21% (from 22.08 km/h to 26.71 km/h).

The three indicators above were investigated at an individual link level. Detailed results for delay are presented (Figure 4) since they are clearer. As expected, delay improvement was not uniform, some links had a greater reduction, while others experienced an increase.

In general, the links with more lanes had greater improvement (reduced delay). However, for the links with two lanes, the delay was less reduced than for the links with a single lane. Another interesting point was that the left-turn traffic had better improvement in a delay overall, especially for single lane links.

The links with three or more lanes have a dedicated lane for left turns, while the links with a single and two lanes do not. For single lanes, vehicles drive one by one at intersections with a simple green light for all directions, so that AVs can improve traffic flow in general. On the other hand, for links with two lanes, there would be a conflict between vehicles turning left and those moving forward, depending upon traffic signal phase settings.

In terms of stop frequency at intersections (Table 3), vehicles made 2.67 stops on average for the penetration of 0% and 2.1 stops for the 100% penetration. The stop frequency decreased, as the penetration rate increased, for both AVs and HDVs, with HDVs stopping slightly less than AVs. HDVs stopped 2.67 times for the penetration rate of 0% and 1.85 times for the penetration rate of 80%. AVs stopped 2.4 times for the penetration rate of 20% and 2.07 times for the penetration rate of 80%.

TABLE 1: Parameters for modelling AVs and HDVs.

Parameters		AVs	HDV	
Car-following (Wiedemann 74)	Standstill distance (m)	0.5	1.5	
	Headway time (s)	0.5	0.9 ± 0.2	
Lane change	Min. headway (m)	0.2	0.5	
	Safety distance reduction factor (%)	30	60	
	Cooperative lane change      Min. speed difference(km/h)	10	N/A	
	Max. collision time (s)	10	N/A	
Driver characteristics	Look ahead distance (m)	Min.	0	5
		Max.	500	100
	Look back distance (m)	Min.	0	5
		Max.	500	50
	Desired speed (km/h)	Lower bound	50	48
Upper bound		50	58	
	Driver errors (%)	0	10	
Automated driving/platooning possible	Max. number of vehicles	7	N/A	
	Max. desired speed (km/h)	50	N/A	
	Max. distance for catching up to a platoon (m)	30	N/A	
	Gap time (s)	0.2	N/A	
	Minimum clearance (m)	2	N/A	

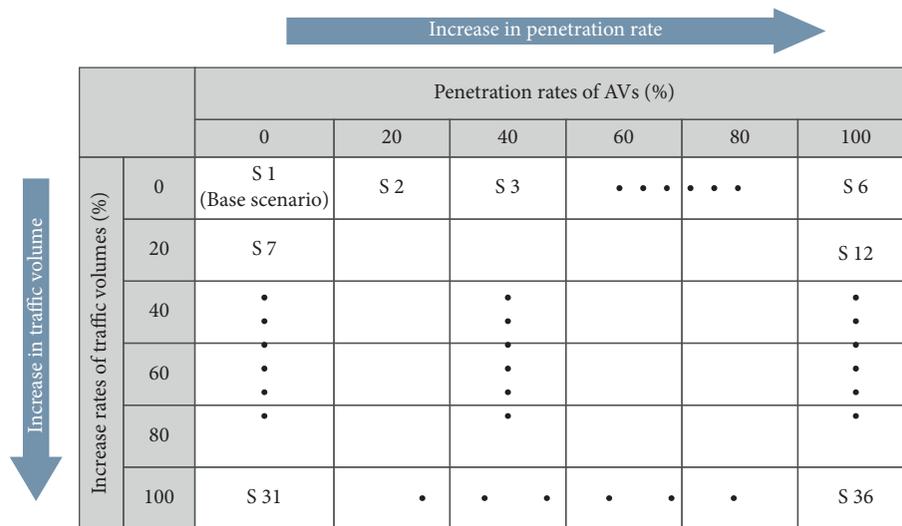


FIGURE 2: Scenario matrix.

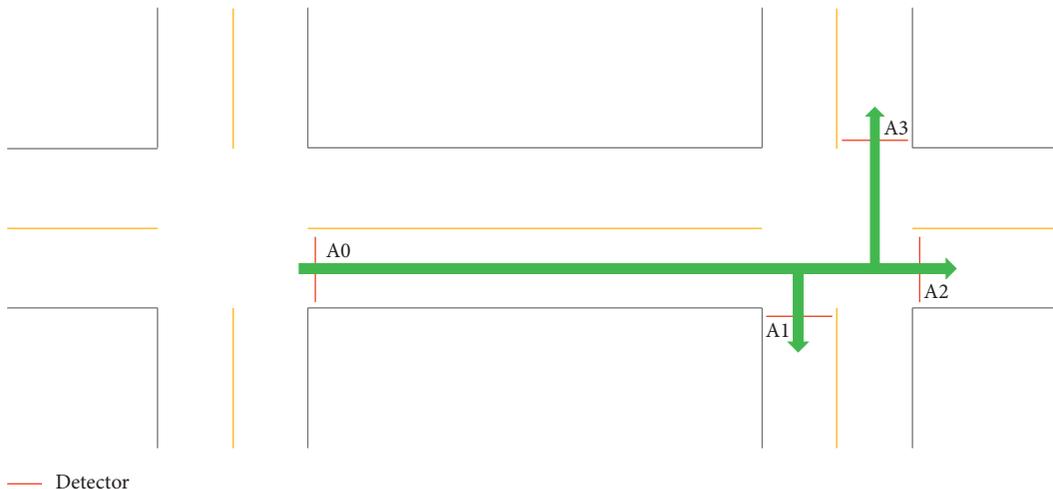


FIGURE 3: Location of detectors.

TABLE 2: Summary of road network performance by AV penetration rate.

Penetration rate (%)	Avg. travel time (s)	Avg. delay time (s)	Avg. vehicle speed (km/h)
0	229.99	126.65	22.08
20	213.18	109.71	23.88
40	204.21	100.88	24.92
60	198.95	95.91	25.56
80	194.46	91.82	26.12
100	189.75	87.74	26.71

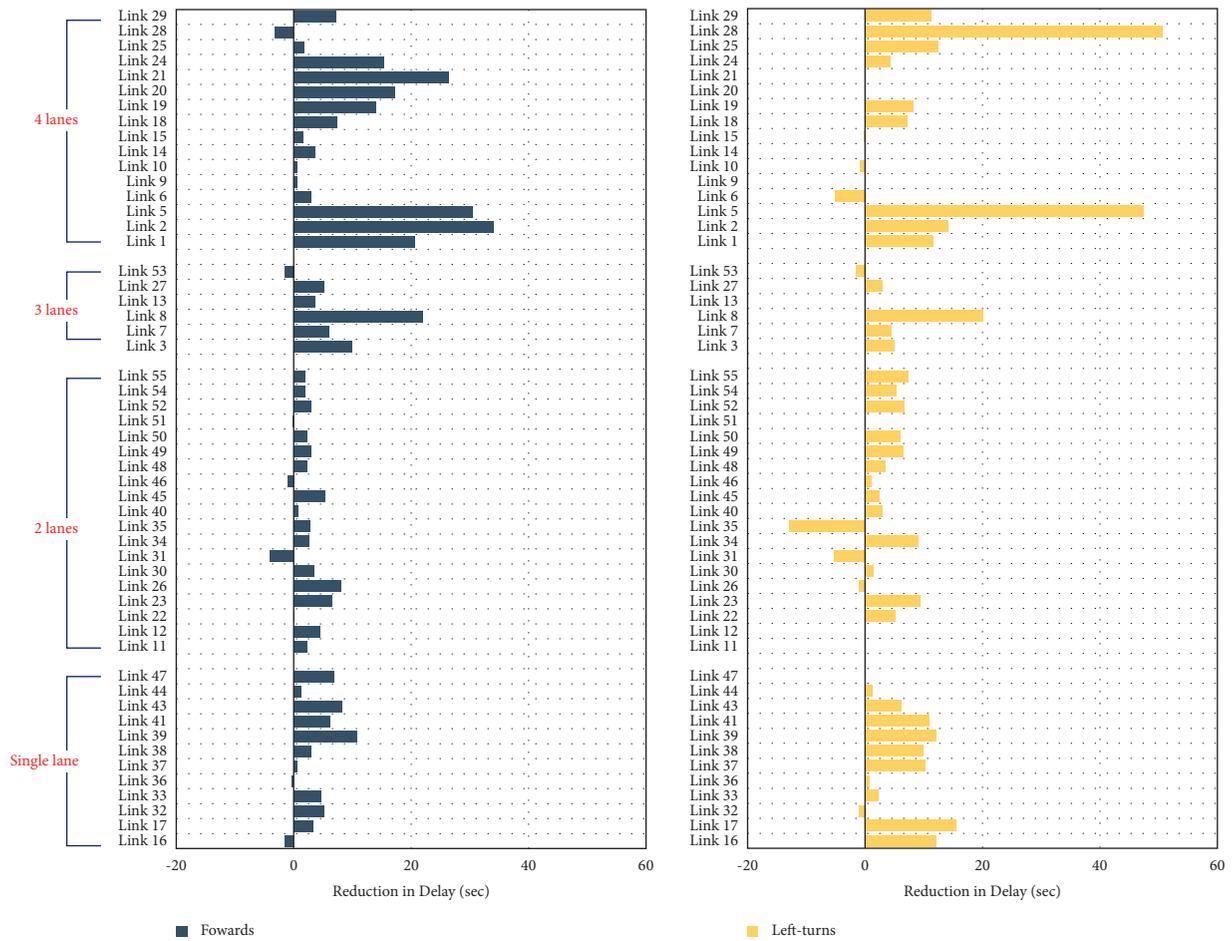


FIGURE 4: Reduction in delays of the links by lane numbers at 100% penetration rate.

Interestingly, the stop frequency for AVs increased slightly to 2.1 stops for the penetration rate of 100%, though there is no significant difference between 2.07 and 2.1. Further analysis found that the stop frequency for AVs increased at a penetration rate of 84%. The difference between HDVs and AVs in the stop frequency seems to be influenced by the value of the parameter of desired speed. The desired speed of AVs was set at 50 km/h, but the speed of HDVs varied from 48 to 58 km/h, so HDVs could drive more quickly and aggressively with a small violation of traffic signals.

4.2. Impact of AV Penetration Rate and Traffic Volume Increase on Traffic Flow. This section details the effect of AV

penetration rate and traffic volume increase on traffic flow. The impact on average travel time, average vehicle speed, and the average delay is presented in Figure 5.

Average travel time, average vehicle speed, and average delay increased dramatically as traffic volume increased. However, this was suppressed by an increase in the AV penetration rate. For example, as the traffic volume increased and the penetration rate remained at 0% (orange line), the average travel time increased by 158% (from 229.99s to 592.24s). On the other hand, when the traffic volume increased and the penetration rate remained at 100% (dark blue line), the average travel time increased by 91% (from 189.75s to 362.95s). In terms of the average delay, the changes were more significant. When the penetration rate was 0% and traffic volume increased, the average delay

TABLE 3: Stop frequency at intersection by AV penetration.

Penetration rate (%)	HDVs	AVs	Average
0	2.67	—	2.67
20	2.19	2.4	2.23
40	2.03	2.17	2.09
60	1.96	2.1	2.04
80	1.85	2.07	2.03
100	—	2.1	2.1

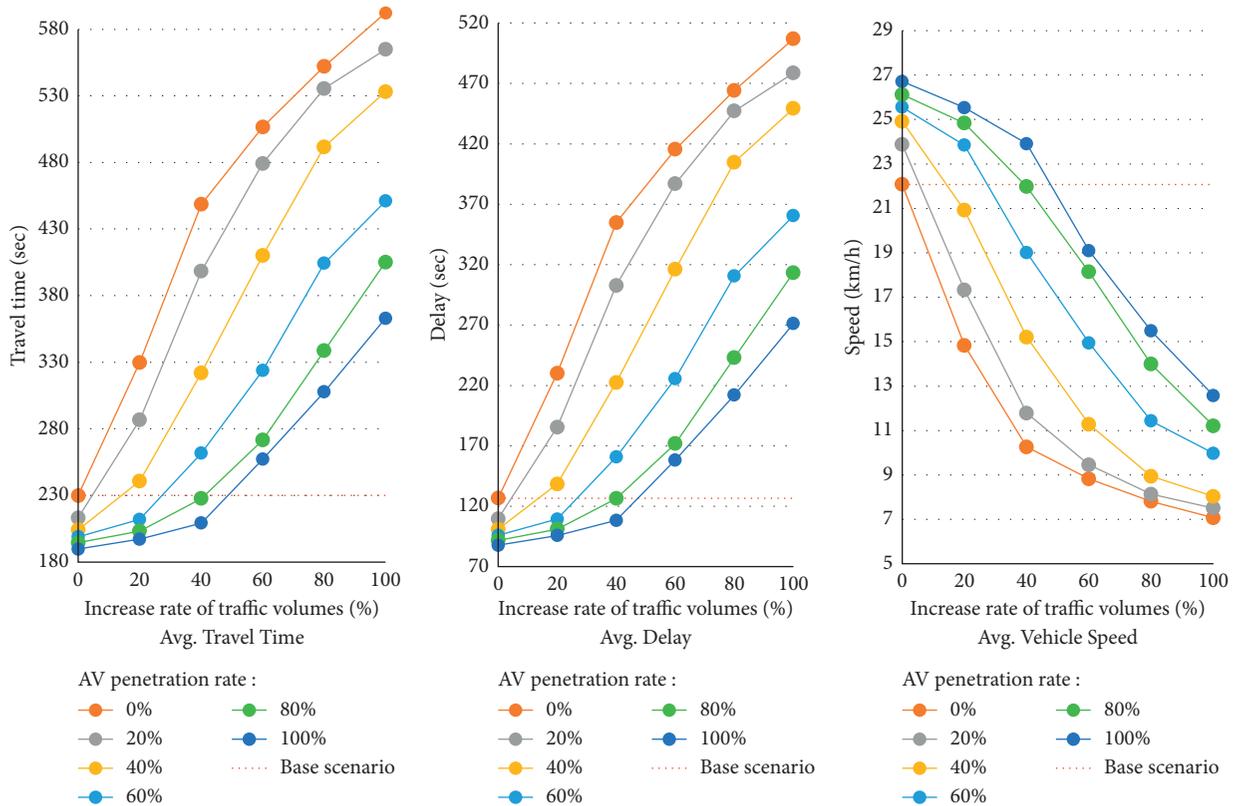


FIGURE 5: Traffic flow by AV penetration rate and traffic volume increment.

increased by 336% (from 109.71 s to 478.65 s), while at the penetration rate of 100%, it changed by 209% (from 87.74 s to 271.15 s). The change of the average speed also showed a similar pattern, where the increase of AV penetration rate dramatically mitigates worsening traffic conditions by traffic volume increase.

In addition, the distances between the lines on the y-axis were getting greater as the traffic volumes increased (x-axis) and then getting narrower again. For example, as traffic volume increased from 0% to 100% by 20%, differences between the average travel time for the penetration rate of 0% and of 100% were 40.24 s, 132.75 s, 239.43 s, 249.41 s, 244.48 s, and 229.28 s, respectively. At the penetration rate of 60%, the mitigation effect by AVs on travel time increase by traffic volume was most intensive.

Automated vehicles reduce the pressure from increased traffic volumes. This means that, without building more roads, road network capacity will increase as the number of AVs increases. For example, in the graph of average travel

time in Figure 5, the red dotted line is the current average travel time of the network (229.99 s). The red dot line can be set as a limit of upper acceptable travel time for worsening traffic flow by increased traffic volumes. In the graph of average travel time in Figure 5, when the penetration rate was 100%, the average travel time was still below the red dot line. This means the road network can accommodate 50% more traffic volume.

**4.3. Discussion: AVs, Traffic Flow, and Road Capacity.** So far, the results indicate that introducing AVs will have the potential to improve traffic flow, even on urban roads. For the case study areas, the travel time decreased by 17% when the penetration rate was 100%. They also showed that traffic flow could be improved, even with a low penetration rate. When the penetration rate was 20% without traffic increase, the average travel time decreased by 7% and the average delay decreased by 13%, while the average speed increased by

8%. This improvement will be possible due to shorter headway, better sensor system, and less errors of AVs compared to HDVs. Probably, it will be because of the parameter setting for more aggressive driving behaviors, based on assuming better and more accurate driving ability of AVs.

However, there is still a debatable point. Some studies report that traffic flow will become worse with a low or medium AV penetration rate, between around 20% and 70% [5, 7, 8, 15, 28]. The studies considering vehicles on highways with ACC emphasized that AVs would make it possible to reduce headway between vehicles and that this will lead to an improvement in traffic flow and even road capacity. Conversely, few studies were performed for urban roads. Lu et al. [17] investigated the impact of AVs on urban roads. They found that, with a penetration increase from 0% to 100%, there was an improvement of 16% in traffic flow in an artificial grid network, while an improvement of 23.8% was found for the real-world network. Their study did not show a negative impact on the traffic volume at a low AV penetration rate and indicated that the impact of AVs would differ depending on road categories.

The study found that road capacity will increase by AVs even on urban roads. A few other studies showed a similar capacity increase by 20~25% in the urban roads (interrupted flow) due to an increase in the AV penetration rate [13, 17, 24]. However, 20~40% increase in road capacity on urban roads seems rather low compared to the increase of 80% on highways (uninterrupted flow) [40]. This will be due to traffic signals at the intersections and the intersections themselves. Vehicles on urban roads must wait for their right of way at an intersection. Halting at an intersection and waiting for a green signal causes delay, regardless of AVs or HDVs. Under a mixed condition of AVs and HDVs, traffic signals will be necessary at most intersections. Although all vehicles on roads will be AVs in the future, they would wait for their turn to pass through an intersection. This would reduce the benefit of AVs on urban roads.

## 5. Conclusions

The study investigated the impact of AVs on traffic flow and road capacity. The study adopted a case study with a real-world network and a microsimulation approach using VISSIM to simulate the accurate behaviors of vehicles, interactions among vehicles, and movements by traffic signals in an urban road network. The team collected traffic data on-site and traffic signal data from a local council. The parameters were set for AV behaviors at SAE level 4, based on previous studies [28, 30, 37, 38]. However, a few possible AV features, for example, V2V communication, were not implemented in the simulation. A total of 36 scenarios were simulated. Among them, 6 scenarios were to consider the increase of only AV penetration rate from 0% to 100%, with 20% increment. The other 30 scenarios took account of both the AV penetration rates and traffic volume increase (also from 0% to 100%, with a 20% increment).

As expected, AVs have the potential to improve traffic flow and reduce the burden of traffic volume increase. The

results showed that AVs improved traffic flows by decreasing travel time and delay and increasing vehicle speed. As the penetration rate increased, the improvement also increased. For the penetration of 100%, there was an average travel time saving of 17%, delay reduction of 31%, and vehicle speed improvement of 21%. Analysis at the link level indicated that the links with three or more lanes had more traffic flow improvement than the links with one or two lanes.

The study also found that AVs reduce worsening traffic flow. However, if using AVs leads to increased demand for car use, AVs will become a potential risk regarding traffic management. However, when all the vehicles are AVs, the current road network could afford 40% more traffic, without building extra roads and worsening traffic conditions.

Although there is huge interest and investment in AV-related technologies, it is still unclear how AVs would improve the future transport system. Most of the previous studies investigated the impact of AVs in the case of highways. However, despite most car use taking place in urban areas, studies for urban roads have rarely been done.

This study indicated that even a low penetration rate of AVs can improve traffic flow on urban roads. Moreover, as AVs can improve road network capacity by 40%, transport planners or policymakers should consider AVs for planning transport systems for the future, probably over 15 or 25 years. With car-sharing trends and shared automated vehicles (SAVs), planners need to rethink issues around car use and road capacity. Probably, there will be an overcapacity of current road networks for car use demand in the future. In that case, city planners need to redesign roads for cities or to find another use for the spare capacity achieved by using AVs.

Although the study tried to investigate the impact of AVs on urban roads, there were many limitations. The parameters in the model need to be more accurately calibrated. For example, the 15% error in passing traffic counts, between model-generated counts and field data, was relatively large and could be improved on. The calibration was also carried out focusing on main corridors, so minor corridors were not as well-calibrated. The study assumed the homogeneous behavior of AVs. In the study, AVs were set to drive more aggressively than HDVs because they were believed to have better sensors and more accurate steering ability. However, another possible behavior is being more cautious to reduce the possibility of accidents. Another limitation was the changes in vehicle behaviors by interactions between AVs and HDVs, in that AVs will influence HDVs under a mixed condition of AVs and HDVs. Ramati et al. [41] reported that human drivers' behaviors will change when they are following AVs. They found that human drivers felt more comfortable with following AVs than HDVs. However, our study assumed that HDVs were not affected by the existence of AVs and the increased penetration, so the next step will be to reflect human drivers' behavior changes by introducing AVs in microscopic simulation models [41]. There was a debatable point regarding the improvement of traffic flow at low penetration rates, around 20~40%. Many researchers forecast a confusing period as AVs and HDVs will be mixed on roads for a long time. The study did not show such a

result, although this could be a matter of parameters or calibration.

## Data Availability

The VISSIM data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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