Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 72 (2023) 3062–3069

Transportation Research Procedia

www.elsevier.com/locate/procedia

Transport Research Arena (TRA) Conference

Impacts of on-street parking regulations on cooperative, connected, and automated mobility - a traffic microsimulation study

Hua Sha[a]*, Rajae Haouari[a], Mohit Kumar Singh[a], Evita Papazikou[a], Amna Chaudhry[a], Pete Thomas[a], Mohammed Quddus[b], Andrew Morris[a]

[a]*Transport Safety Research Centre, School of Design and Creative Arts, Loughborough University, Loughborough LE11 3TU, UK*
[b]*Imperial College, Exhibition Rd, South Kensington, London SW7 2BX, UK*

Abstract

This study aims to investigate the mobility impacts of on-street parking regulations for Connected and Automated Vehicles (CAVs) under mixed traffic fleets. A calibrated and validated network model of the city of Leicester in the UK was selected to test the implementation under various deployment scenarios. The modelling results indicated that replacing on-street parking with driving lanes, cycle lanes and public spaces can potentially lead to better traffic performance (27% to 30% reduction in travel time, 43% to 47% reduction in delays) compared to the other tested measures. The less significant impact of replacement with pick-up/drop-off points is due to increased stop-and-go events while vehicles pick-up and drop-off passengers, consequently leading to more interruptions in the flow and increased delays. The paper provides examples of interventions that can be implemented for on-street parking during the implementation of CAVs for regional decision-makers and local authorities.

Keywords: On-street parking; Connected and autonomous vehicles; Traffic microsimulation; Delays; LEVITATE

1. Introduction

Cooperative, connected and automated mobility (CCAM) services, and a host of associated computing advances, will allow the unprecedented capability to collect, exchange and analyse large volumes of data for optimal decision making at the individual, local and city levels and will therefore increasingly revolutionise our economy and society over the next decade. On-street parking has some natural economic contributions (e.g., parking charges revenue). However, the adverse effects have drawn the attention of governmental bodies and academic institutions following increased congestion, capacity reduction and increased road traffic accidents. The premise of CCAM services was that the introduction of connected and autonomous vehicles (CAVs) may result in a reduction of parking requirements

---

* Corresponding author. Tel.: +44 (0)1509 226947;
E-mail address: h.sha@lboro.ac.uk

10.1016/j.trpro.2023.11.855

since CAVs may be capable of dropping a passenger off close to their destination then continuing either to another passenger or returning to base or a more suitable parking location. Therefore, city administrations could decide to change the purpose of a roadside parking lane to alternative purposes as public space. A review of existing literature also suggested that the introduction of autonomous vehicles offers the potential to improve road safety and reduce the urban space requirements for roads and parking, and this opens up new opportunities to create more space for high-quality and liveable areas (González-González, Nogués and Stead, 2020). The lack of real-world data from CAV operations at a network- or a corridor-level makes it challenging to examine how on-street parking regulations for CAVs affect a transport network. Recent research has, therefore, relied on a traffic microsimulation platform.

In this regard, this study aims to investigate the traffic performance of on-street parking regulations under mixed traffic fleets including human-driven vehicles and connected and automated vehicles based on various market penetration rates. As part of the LEVITATE (Societal level impacts of connected and automated vehicles) project, this paper provides the methodology and key findings in evaluating the mobility impacts of on-street parking regulations for CAVs in terms of travel time, delay time, average speed and distance travelled. LEVITATE is a European Commission supported H2020 project that aims to develop a new impact assessment framework that would help European cities, regions and policymakers to prepare and manage the introduction of automated vehicles in passenger cars, urban transport services and urban logistics (LEVITATE, 2021).

2. Literature review

On-street parking can significantly impact traffic performance and may create or exacerbate various problems for urban cities. In this respect, a recent study conducted by Haider et al. (2021) revealed the effects of on-street parking in Chittagong City, Bangladesh, where on-street parking can have the following adverse effects: narrows down the road (47%), footpath crisis (29%), noise and air pollution (23%), shops get blocked (5%), and loss of time (30%). Regarding travel time, Guo et al. (2012) applied the hazard-based duration model and attempted to quantify the influential factors related to on-street parking by observing 938 vehicles in two-lane, two-way streets. The results showed that on-street parking has a significant impact on travel time and factors that influence it are the following: the distribution of travel time, the effective lane width, and the frequency of parking/unparking manoeuvres. Similarly, Lim et al. (2012) used the analytical survey and the experimental method in Metro Manila. The results revealed that the manoeuvring of vehicles in and out of an on-street parking space had increased the travel time of moving vehicles. A recent study by Putri and Prahara (2021) utilised the Manual Kapasitas Jalan Indonesia (MKJI) 1997 and a linear regression model and reported that on-street parking has a strong influence on the travel time of the vehicle to get through to the study area.

Several studies that investigated the relationship between on-street parking and traffic delay. Nahry et al. (2019) examined the effect of on-street parking in Jakarta by modelling the relationship between various variables, i.e., parking turnover, parking index, flow-in and flow-out. The modelling results showed that the variable of parking turnover has a significant impact on traffic delay. In other words, the higher the volume and the parking turnover, the higher the delay will be. A similar finding was reported by Borovskoy and Yakovleva (2017). The authors developed a dynamic simulation model that integrated AIMSUN software with Vehicle Tracking application for AutoCAD to study parking turnover impact on traffic flow delay. The results revealed that the increase in the on-street parking turnover leads to an increase in traffic delays. Sugiarto and Limanoond (2013) examined the impact of on-street parking manoeuvres on travel speed and capacity, particularly on urban artery roads in the city of Banda Aceh. The traffic simulation showed that with the presence of on-street parking, the average delay time was increased by 32% and the speed was reduced by 24%.

Various research studies indicated that the introduction of CAVs has the potential to reduce the urban space requirements for roads and parking (Cavoli et al., 2017; Anderson et al., 2016; Fagnant et al., 2015), and creating more space for the high-quality, liveable area (Gonzalez et al., 2020), especially in the context of shared autonomous vehicles (SAVs) that could reduce the number of the required parking spaces due to serving customers at different times (Othman, 2021). Consequently, a large number of existing parking spaces will be gradually removed or replaced or converted for other purposes, e.g., green and recreational spaces (Xia et al., 2021; Milakis et al., 2017). A recent study conducted by Xia et al. (2021) reviewed the current research on urban public parking spaces under the scenario of SAVs and proposed four key issues which involved: (a) how much to renew, (b) when to renew, (c) what to renew and (d) how to update. The main finding was that many parking spaces would be renovated and transformed for other uses in the SAV era. A report conducted by International Transport Forum (2015) investigated the microsimulation of the SAVs in the city of Lisbon, Portugal. The results showed that under a fully shared automated vehicle fleet scenario, both on-street and off-street parking spaces could be significantly reduced between 84% and 94%. A reduction of over 90% was also reported by Zhang et al. (2015), who used an agent-based simulation model of the SAV system to quantify the space-saving. The results also indicated that the amount of urban parking spaces saved could be converted into more sustainable designs, such as green, open, and human-oriented spaces. A study by Silva et al. (2021) investigated the transformation between SAVs and urban spaces, by implementing the method of building scenarios in a case study in Budapest, Hungary. The results indicated that almost 83% of the parking demand could be reduced, and relevant urban spaces can be renovated for other purposes. The results also showed that SAVs could significantly minimise air pollution caused by parking infrastructure and up to 45% reduction can be achieved.

According to the findings from the previous researchers, on-street parking can potentially cause some negative impacts on traffic performance in the urban area, i.e., by reducing road capacity, increasing journey time, increasing delay time, and causing congestion. The introduction of CAVs could have the potential to mitigate some of the negative impacts with suitable on-street parking regulations as well as provide new opportunities in the cities for high-quality and liveable areas. The previous studies also suggested that the on-street parking spaces should be more dynamically managed and re-used.

3. Methodology

3.1. Network and model

A calibrated and validated traffic network model developed in AIMSUN Next microsimulation was used in this study. The Leicester city centre network is provided by the Leicester City Council (UK), and the modelling area is around 10,2km² consisting of 788 nodes, 1,988 sections and an OD matrix of 209×208 centroids. The traffic demand for passenger cars, large goods vehicles (LGVs) and heavy goods vehicles (HGVs) is 23,391 trips, 3,141 trips and 16 trips, respectively. The network is presented in Fig. 1a. This specific network only includes the city centre area. For practical purposes to be more effective using simulation, on-street parking in the city centre has been divided into 4 parking zones, including 52 streets with 138 parking bays, as shown in Fig. 1b.

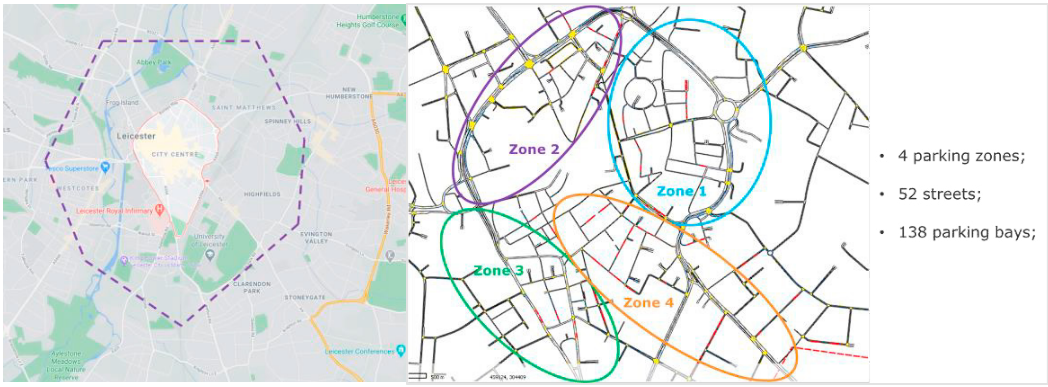


Fig.1. (a)The Leicester city centre network and (b) on-street parking zones in AIMSUN software

Within this SUC, six scenarios will be studied using microscopic simulation:

- Baseline scenario – fleet penetration of CAVs increasing without replacing the on-street parking intervention. A total of 52 streets with 138 parking bays for all 4 parking zones were included.
- Removing half of the on-street parking spaces – The scenario is based on reducing parking capacity. The on-street parking spaces have been reduced from 138 to 79 parking bays after removing half of the parking spaces in each of the four parking zones.

- Replacing on-street parking spaces with driving lanes. In this scenario, on-street parking spaces will be converted to driving lanes (shown in Fig. 2).
- Replacing on-street parking spaces with cycling lanes. In this scenario, on-street parking spaces will be converted to a dedicated cycle lane (shown in Fig. 2). The cyclist behaviour has not been simulated in the modelling.
- Replacing on-street parking spaces with pick-up and/or drop-off points (shown in Fig.2). The scenario assumes the AVs are SAVs. As a result, after the vehicle pick-up or drop-off the passenger, the vehicle will exit the study area to return home or serve another customer.
- Replacing on-street parking spaces with public spaces. In this scenario, on-street parking spaces will convert to public spaces, e.g., green and recreational spaces (shown in Fig. 2).

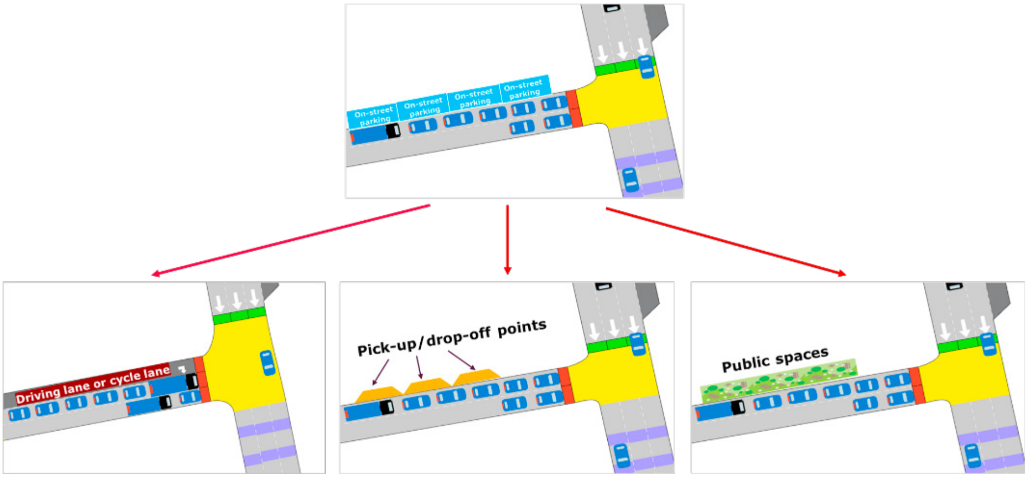


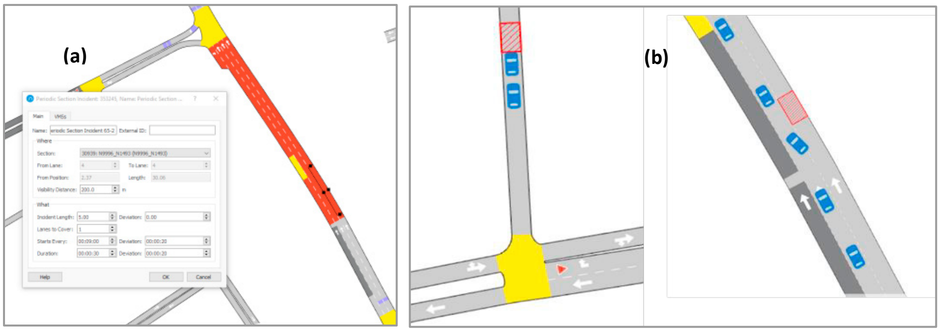
Fig. 2. Replacing on-street parking with driving lanes, cycle lanes, pick-up and/or drop-off points and public spaces

The following assumptions and limitations exist in this study implementation:

- All CAVs are assumed to be EVs, and human-driven vehicles are assumed to be non-electric vehicles;
- Simulations are run for lunchtime rush hour, considering it to be the most critical period for this study;
- No residential parking is considered in the model;
- No changes have been considered in the number of locations of disabled on-street parking bays;
- The pick-up/drop-off scenario was assumed to follow the SAVs concept;
- Cyclists are not modelled in replacing on-street parking spaces with cycling lanes scenario due to the software limitations and lack of model calibration.

3.2. Modelling on-street parking manoeuvres

Within this study, the function of the periodic section incident has been applied to simulate the on-street parking manoeuvres (shown in Fig. 3a). It is represented in the simulation as if it were a traffic incident that causes a lane blockage over a certain period. This action creates random incidents and is placed randomly throughout the area, i.e., in streets and parking bays (Aimsun, 2021). On-street parking manoeuvre duration (blockage time) is assumed to be the 30s with a 20s deviation. The obstructions (frequency of incidents) were created at regular time intervals (e.g., 3, 5, 8, 13, 17, 22, 27, and 31 minutes) and depending on the length of the parking bay. Both parking manoeuvre duration and obstruction were based on the previous literature (Chai et al., 2020; Borovskoy and Yakovleva, 2017; Portilla, Oreña, Berodia, & Díaz, 2009). Fig. 3b illustrates examples of the periodic section incident representing on-street parking on a single lane and a multi-lane road in the model using the AIMSUN Next simulation platform. The left image demonstrates the incident (on-street parking) happening on a single lane blocking the traffic over a certain time. The right image shows the incident happening on a multi-lane road where the following vehicle decides to change lane because of the leading vehicle making an on-street parking manoeuvre.



Periodic Section Incident: 353245, Name: Periodic Section ...

Name: eriodic Section Incident 65-2
External ID:
Section: 30938: N9996_N1493 (N9996_N1493)
From Lane: 4
To Lane: 4
From Position: 2.37
Length: 30.06
Visibility Distance: 200.0 m
Incident Length: 5.00
Deviation: 0.00
Lanes to Cover: 1
Starts Every: 00:09:00
Deviation: 00:00:20
Duration: 00:00:30
Deviation: 00:00:20

Fig. 3. (a)Screenshot of periodic section incident in AIMSUN Next (b) Periodic section incident on a single lane and multi-lane road

3.3. CAV parameters and deployment scenarios

Two types of CAVs were considered in this study: 1st Generation (Gen) CAVs and 2nd Gen CAVs. Both types are assumed to be level 5 fully autonomous vehicles. Modelling these two types is based on the assumption that technology will advance over time. As a result, 2nd Gen CAVs will have enhanced sensing and scenario identification capabilities as well as improved decision-making, driving characteristics, and incident anticipation, among other things. The following are the main assumptions in general on CAVs characteristics that were used in the LEVITATE project:

- 1st Gen: limited sensing and data processing capabilities, long gaps, early anticipation of lane changes than human-driven vehicles and longer time in give way situations.
- 2nd Gen: advanced sensing and data processing capabilities, data fusion usage, small gaps, early anticipation of lane changes than human-driven vehicles and less time in give way situations.

The CAV parameters used in this study were derived from the LEVITATE project. The details on the parametric assumptions and values of key parameters can be found in a study by Chaudhry et al. (2022). CAV deployment was tested from 0 to 100% MPR with 20% increments as shown in Table 1. The simulation duration of each scenario was one hour (lunchtime rush hour 12:00-13:00) with a warm-up time of 20 minutes. For each scenario, 10 replications with different random seeds were simulated in order to replicate the stochastic nature of the traffic flow. The simulation time step was 0.1 seconds.

Table 1. CAV Deployment scenarios in LEVITATE project

Type of Vehicle	CAV Deployment Scenarios							
	100-0-0	80-20-0	60-40-0	40-40-20	20-40-40	0-40-60	0-20-80	0-0-100
Human-Driven Vehicle - passenger vehicle	100%	80%	60%	40%	20%	0%	0%	0%
1st Gen CAV - passenger vehicle	0%	20%	40%	40%	40%	40%	20%	0%
2nd Gen CAV - passenger vehicle	0%	0%	0%	20%	40%	60%	80%	100%
Human-Driven LGV	100%	80%	40%	0%	0%	0%	0%	0%
LGV-CAV	0%	20%	60%	100%	100%	100%	100%	100%
Human-Driven HGV	100%	80%	40%	0%	0%	0%	0%	0%
HGV-CAV	0%	20%	60%	100%	100%	100%	100%	100%

4. Analysis and results

In this study, the mobility-related impacts have been analysed through microscopic simulation. These impacts include travel time, delay time, average speed and distance travelled, and are presented in Fig. 4 and Table 2.

As shown in Fig. 4, under no policy intervention, with increasing CAVs in the network some irregular patterns can be identified with regard to the impact on travel time and delay time. At higher MPRs, in general, the travel time and delay were found to decrease as the CAVs market penetration rate increases both in baseline and under all tested interventions. In other words, less journey time and less delay are needed for higher CAVs market penetration rates.

It is in line with the finding of some previous studies showing that autonomous vehicles can maintain a more consistent speed while allowing vehicles to accept much shorter headways to achieve the best performance in the traffic stream (Almobayedh, 2019; Li et al., 2019; Stogios et al., 2019). The results also show a decrease in travel time and delay time due to various parking space regulations compared with the no policy (baseline) intervention scenario.

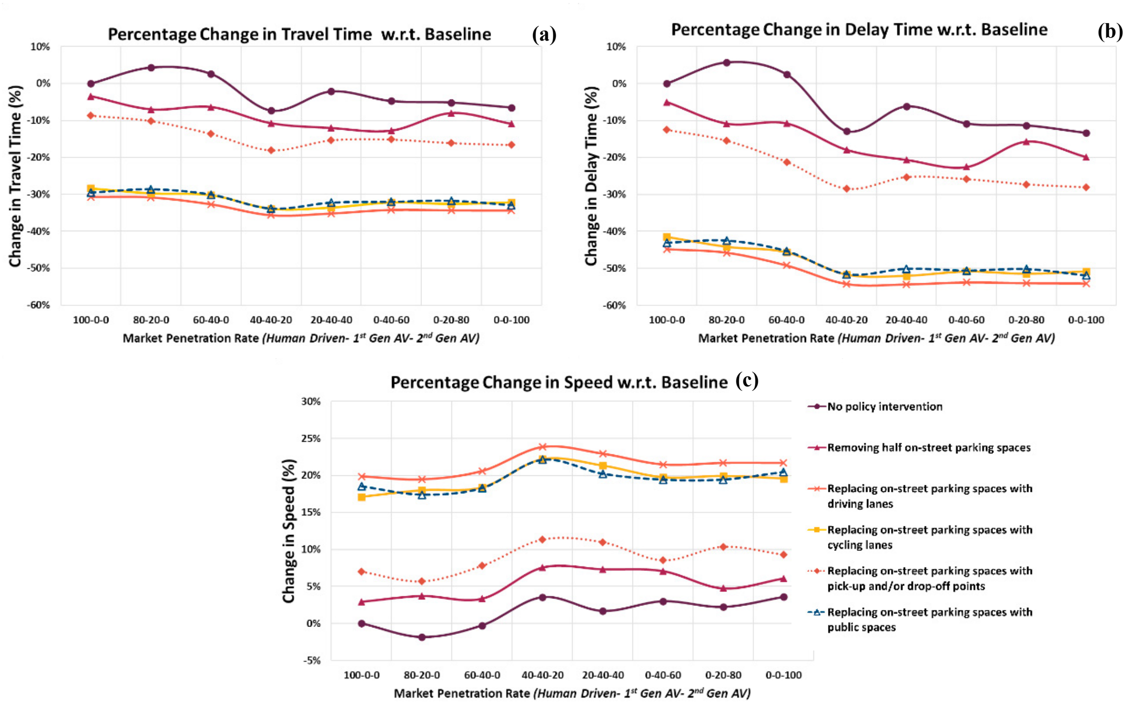


Fig. 4. Impact on (a) delay time, (b) travel time and (c) average speed due to MPR of CAVs and interventions for parking space regulations

The impact of each of the individual interventions can be clearly seen in Fig. 4, where travel time (Fig. 4a) and delay time (Fig. 4b) are calculated as a percentage change compared to the value in the corresponding of the current situation (100-0-0 with no policy intervention). The interventions of replacing on-street parking with driving lanes, cycle lanes and public spaces have shown a significant improvement in reducing the travel time and delay time compared to the baseline scenario. Between 27% to 30% reduction in travel time and 43% and 47% reduction in delay time can be achieved for these three interventions, respectively. The results also show that the impact due to removing half of the on-street parking spaces and replacing on-street parking spaces with pick-up/drop-off areas has relatively less impact on travel time and delay time compared to the other policy interventions. One of the most important potential reasons is that the interventions of removing half of the on-street parking spaces and replacing them with pick-up/drop-off points may cause queues built-up near those areas due to frequent parking manoeuvres or while vehicles picking up and dropping off passengers, resulting in an increased congestion, delays and increased travel time. This finding is consistent with the observations by other studies (Winter et al., 2021; Chai et al., 2020). The results also suggest that replacing half of the on-street parking spaces may not provide the expected improvement in the city centre, especially with a congested network. It is worth noting that the least travel time and delay time occurs in the mixed scenarios, i.e., 40-40-20 for baseline and other interventions. The results of average speed (shown in Fig. 4c) in this study demonstrated that higher average speeds were recorded in this scenario, resulting in reduced delay times and travel times in the traffic network.

Within Levitate, the amount of travel is defined as the person kilometres of travel per year in an area. The impacts between the interventions are shown in Table 2., where the total distance travelled for vehicles is calculated as a percentage change comparing to the value in the corresponding of current situation (100-0-0 with no policy intervention). It can be clearly seen that the interventions of replacing on-street parking with driving lanes, cycle lanes and public spaces show a general increased distance travelled compared to the baseline scenario. In contrast, the interventions of removing half of the on-street parking spaces and replacing them with pick-up/drop-off points have decreased the distance travelled compared to the baseline scenario. For example, the total distance travelled has been reduced by around 9% and 7% at 0-20-80 scenarios for the interventions of removing half of the on-street parking spaces and replacing them with pick-up/drop-off points, respectively. One of the most important potential reasons is that the interventions of removing half of the on-street parking spaces and replacing them with pick-up/drop-off points may often create stops and queues in the traffic stream due to frequent parking manoeuvres or vehicles picking up and dropping off passengers and leading more congestions and delays. Also, the interventions of replacing on-street parking with driving lanes, cycle lanes and public spaces have a better traffic performance in the network compared to those with removing half of the on-street parking spaces and replacing them by pick-up/drop-off points, i.e., less delay, less travel time and increased traffic flow. In other words, more vehicles enter the network which in turn increase the total distance travelled.

Table 2. Percent Change in total distance travelled w.r.t corresponding Baseline for parking space regulations SUC

CAVs Penetration Rate	No policy intervention	Removing half on-street parking spaces	Replacing with driving lanes	Replacing with cycling lanes	Replacing with pick-up and/or drop-off points	Replacing with public spaces
100-0-0	0%	-9%	11%	11%	-15%	10%
80-20-0	-2%	-6%	11%	11%	-1%	11%
60-40-0	-11%	-7%	9%	10%	-6%	9%
40-40-20	9%	-7%	12%	9%	-3%	11%
20-40-40	-2%	-5%	11%	12%	-17%	10%
0-40-60	-9%	-5%	12%	8%	-3%	12%
0-20-80	2%	-9%	12%	12%	-7%	12%
0-0-100	-6%	2%	13%	12%	-2%	12%

5. Conclusion and future works

This paper discusses the microsimulation approach adopted to evaluate the mobility impacts (i.e., travel time, delay time, distance travelled and average speed) of various on-street parking regulations with the introduction of CAVs under the mixed traffic fleet compositions. The modelling results indicated that replacing on-street parking with driving lanes, cycle lanes and public spaces can potentially lead to better traffic performance (27% to 30% reduction in travel time, 43% to 47% reduction in delays) as compared to the other tested measures, including removing half of the parking spaces and replacing on-street parking with pick-up/drop-off spaces. The less significant impact of replacement with pick-up/drop-off spaces is due to increased stop-and-go events while vehicles pick-up and drop-off passengers, consequently leading to more interruptions in the flow and increased delays. Therefore, dynamic pick-up/drop-off points could be introduced in the network to mitigate this impact as an improvement measure. The results from the microsimulations showed an increase in travelled distance when on-street parking spaces were replaced with driving lanes, cycle lanes, and public spaces compared to the baseline scenario as well as the other tested strategies, including 'removing 50% of the parking spaces' and 'replacing pick-up/drop-off' spaces. The main reason behind this is the improved network flow under those parking space regulation schemes where travel distance was found to be increased, allowing more vehicles in the network during the simulation period and consequently increasing the distance travelled. The results also revealed that replacing half of the on-street parking spaces may not provide the expected improvement in reducing delays in the city centre, especially with congested traffic conditions. The paper provides examples of interventions that can be implemented for on-street parking during the implementation of CAVs for regional decision-makers and local authorities.

The findings provide useful insights to city governments and policy makers towards identifying how parking space regulations in the CAV environment can help mitigate potential adverse impacts in the short-term on urban mobility, particularly the increase in delays. An ongoing task is that the integration of these results in the web-based policy support tool (PST) will make the LEVITATE impact assessment framework more user friendly for public authorities and transport planners. Future work includes testing and analysing these impacts on different study areas to identify the variations and transferability of the findings. The validation of the results must be examined and compared when real-world data become available.

Acknowledgements

The present research was carried out within the research project "LEVITATE - Societal Level Impacts of Connected and Automated Vehicles," which received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 824361. We would like to acknowledge Leicester City Council for providing the Leicester network model.

References

Aimsun, 2021. Aimsun Next 20 User's Manual, Aimsun Next Version 20.0.3, Barcelona, Spain. qthelp://aimsun.com.aimsun.20.0/doc/UsersManual/Intro.

Almobayedh, H. B., Eustace, D., & Appiah-Kubi, P., 2019. Simulation of the Impact of Connected and Automated Vehicles at a Signalized Intersection. Road Safety & Simulation International Conference, Iowa city, USA.

Anderson, J. M., Nidhi, K., Stanley, K. D., Sorensen, P., Samaras, C., Oluwatola, O. A, 2016. Autonomous Vehicle Technology: A Guide for Policymakers. Santa Monica, CA: RAND Corporation, 2016. https://www.rand.org/pubs/research_reports/RR443-2.html.

Borovskoy, A., Yakovleva, E. 2017. Simulation Model of Parking Spaces Through the Example of the Belgorod Agglomeration, Transportation Research Procedia, 20, 80–86.

Cavoli, C., Phillips, B., Cohen, T., Jones, P., 2017. Social and behavioural questions associated with automated vehicles: A literature review. London: Department for Transport

Chai, H., Rodier, C., Song, J., Zhang, M., Jaller, M., 2020. The Impacts of Automated Vehicles on Center City Parking Demand (No. NCST-UCD-RR-20-17, UCD-ITS-RR-20-17). University of California, Davis, USA. http://dx.doi.org/10.7922/G2445JSR

Chaudhry, A., Sha, H., Haouari, R., Quddus, M., Thomas, P., Boghani, H., Weijermars, W., Gebhard, S., Singh, M. S., Morris, A., 2022. Evaluating the network-level road safety impacts of connected and automated vehicles in mixed traffic using traffic microsimulation methods. In Transportation Research Board 101st Annual Meeting, Washington DC, USA.

Fagnant, D. J., Kockelman, K. M., Bansal, P., 2015. Operations of Shared Autonomous Vehicle Fleet for Austin, Texas, Market. Transportation Research Record: Journal of the Transportation Research Board, 2536, 98-106.

González-González, E., Nogués, S., Stead, D., 2020. Parking futures: Preparing European cities for the advent of automated vehicles. Land Use Policy, 91, 104010. doi: 10.1016/j.landusepol.2019.05.029.

Guo, H., Gao, Z., Yang, X., Zhao, X., Wang, W.,2012. Modeling travel time under the influence of on-street parking. Journal of Transportation Engineering, 138(2), 229-235. doi: 10.1061/(ASCE)TE.1943-5436.0000319.

Haider, M. A., Islam, M. T., Hasan, S. M., 2021. Exploring the impact of on-street parking in Chittagong City, Bangladesh. International Journal of Building, Urban, Interior and Landscape Technology (BUILT), 17, 17–28. Retrieved from https://ph02.tci-thaijo.org/index.php/BUILT/article/view/242401

International Transport Forum, 2015. Urban Mobility System Upgrade. Retrieved From: https://www.itf-oecd.org/sites/default/files/docs/15cpb_self-drivingcars.pdf

LEVITATE, Societal Level Impacts of Connected and Automated Vehicles, 2021. https://levitate-project.eu/

Lim, M. A., Hallare, E. L., Briones, J. G., 2012. Modeling the Impact of On-street Parking on Vehicular Traffic: Traffic Engineering. LAP Lambert Academic Publishing.

Milakis, D., Van Arem, B.,Van Wee, B., 2017. Policy and society related implications of automated driving: A review of literature and directions for future research. Journal of Intelligent Transportation Systems: Technology, Planning, and Operations, 21.4, 324–348.

Nahry, Agah, H. R., Thohirin, A., Hamid, N. H. A., 2019. Modeling the Relationship between On-Street Parking Characteristics and through Traffic Delay: Parking and Traffic Delay Relationship. Proceedings of the Pakistan Academy of Sciences: A. Physical and Computational Sciences, 56.2, 29-36.

Othman, K., 2021. Impact of autonomous vehicles on the physical infrastructure: Changes and challenges. Designs, 5.3, 40

Portilla, A. I., Oreña, B. A., Berodia, J. L., Díaz, F. J., 2009. Using M/ M/∞ Queueing Model in On-Street Parking Maneuvers. Journal of Transportation Engineering, 13.8, 527-535.

Putri, S. B. K., Prahara, E., 2021. Analysis of the Relationship Between Travel Time and on Street Parking. Turkish Journal of Computer and Mathematics Education (TURCOMAT), 12.3, 5252–5264.

Silva, D., Földes, D., Csiszár, C., 2021. Autonomous Vehicle Use and Urban Space Transformation: A Scenario Building and Analysing Method. Sustainability, 13.6, 3008.

Stogios, C., Kasraian, D., Roorda, M. J., Hatzopoulou, M., 2019. Simulating impacts of automated driving behavior and traffic conditions on vehicle emissions. Transportation Research Part D: Transport and Environment, 76, 176-192.

Sugiarto, S., Limanoond, T., 2013.Impact of On-street Parking on Urban Arterial Performance: A Quantitative Study on Travel Speed and Capacity Deterioration. Aceh International Journal of Science and Technology, 2.2, 63–69. doi: 10.13170/aijst.0202.04.

Winter, K., Cats, O., Martens, K., van Arem, B., 2021. Relocating shared automated vehicles under parking constraints: assessing the impact of different strategies for on-street parking. Transportation, 48.4, 1931-1965.

Xia, B., Wu, J., Wang, J., Fang, Y., Shen, H., Shen, J., 2021. Sustainable renewal methods of urban public parking spaces under the scenario of shared autonomous vehicles (SAV): A review and a proposal. Sustainability, 13.7, 3629. doi: 10.3390/su13073629.

Zhang, W., Guhathakurta, S., Fang, J., Zhang, G., 2015. Exploring the impact of shared autonomous vehicles on urban parking demand: An agent-based simulation approach. Sustainable Cities and Society, 19, 34-45. doi: 10.1016/j.scs.2015.07.006