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Analysing the Impacts of Parking Price Policies with the Introduction of Connected and Automated Vehicles

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Abstract

It is known that parking prices can affect multiple characteristics such as traffic flow, delays, and congestion. Connected and autonomous vehicles (CAVs) do not need drivers and may return to the origin, if necessary, avoiding parking fees. However, if the destination area is not near the origin, it may not be economically viable to return. Hence, in the present study, four scenarios were tested to find the optimal parking strategy: (i) enter and park inside area (ii) enter, drop off and return to the origin (iii) enter, drop off and return to outside parking and (iv) enter and drive around. Different parking prices were used to determine the suitable option. The 'Balanced' scenario with multiple parking choices was found to be better compared to other scenarios, where the flow and travel distance were moderately (-19 and -26.3%) affected. Emissions were reduced significantly with CAVs.

Keywords: parking price; connected and autonomous vehicles; simulation; parking strategies;

1. Introduction

Vehicles are parked for almost 95% of their lifetime (Kondor et al. 2019). Furthermore, the traffic on the roads increases every year in the United Kingdom (U.K.) (Department for Transport, 2017), leading to an increased parking demand at various locations in the city network. Drivers do not easily find a parking space that fulfils specific requirements for their journey. Hence, a significant amount of time is spent searching for an available parking spot (Brooke et al., 2014). It is often impossible to create a parking space and constructing parking spaces on valuable lands increases parking prices. Further, as an increased number of vehicles creates more congestion, pollutant

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emissions and conflicts, policymakers want to discourage the use of private cars. Hence, the traffic on the roads is decreased, leading to improved traffic flow movement on the roadways as vehicles can achieve the free flow speeds in less traffic. Studies have also demonstrated that the reduced traffic due to an increased parking price could also lead to fewer crashes on the roads (Institute for Transport Studies, 2019; Litman, 2012). Hence, fewer parking spaces are created, and vehicle parking charge is enforced (Calthrop et al., 2000; Kelly and Clinch, 2006).

Connected and Autonomous Vehicles (CAVs) do not require parking near their destination as they can return home or relocate to areas with available parking spaces. Studies have been conducted to find the number of parking spaces required for privately owned vehicles (Nourinejad et al., 2018; Zhang and Guhathakurta, 2017). As these vehicles can move without drivers, studies have tried to optimise the parking spaces to accommodate more autonomous cars (Nourinejad et al., 2018). The present study analyses the effectiveness of several parking options available to the vehicles and the consequential impacts on traffic and environmental factors.

The remaining parts of the paper proceed as follows: the second section of this paper provides a short literature review of the study. The methodology of the study is described in section 3. Details of results and discussion are provided in section 4. Conclusions are explained in section 5.

2. Literature review

The cost of parking is an important consideration when determining whether or not to utilise a personal automobile as a means of transportation. According to Transport Statistics Great Britain, around 30 million cars are now registered in the U.K. (Department for Transport, 2017). The need for parking spots will rise as the number of vehicles grows. There may not always be enough parking spots available. Thus, authorities strive to lower the demand for parking spaces and the number of low-occupancy vehicles. For this reason, parking fees were instituted (Institute for Transport Studies, 2019).

Self-driving vehicles can park close to their destination or elsewhere. As a result, there is a range of strategies that city planners could use. In the absence of parking requirements, autonomous vehicles could: 1) roam until a passenger needs them again, 2) return to their origin, or 3) park outside the destination zone. There could also be an intermediate situation in which some vehicles return to parking while others remain in the network.

It is not a novel idea to raise parking fees in order to discourage people from using passenger cars. These have been in use since the 1990s, when they were first introduced to help with space management. 25% of local governments in the United Kingdom attempted to reduce parking spots, according to a survey conducted by Healey and Baker (1998). Furthermore, around half of those polls said that they would raise parking fees.

A stated preference survey was utilised by Simićević et al. (2013) to measure the impact of parking prices on parking utilisation. A correlation was found between parking costs and time limits. The parking price impacts vehicle use, but the time restriction determines whether individuals park on or off-street. It was also discovered that parking prices could assist manage parking spots, but they can also detract from specific areas. Additionally, research has shown that the cost of parking might impact the time it takes to commute (Qian and Rajagopal, 2014)

There is evidence that autonomous cars can save travel time, according to Calvert et al. (2017) as the deployment of self-driving vehicles has been found to minimise travel time. Santana et al. (2021) also found that the journey time is reduced when CAVs are implemented. While Rezaei and Caulfield (2021) found that introducing automated vehicles (CAVs) saves travel time, the trend is not constant and fluctuates.

Cheng and Qi (2019) studied the effect of parking prices on the quality of service at Hongqiao International Airport's parking. The results were examined before and after the parking charge was implemented. This approach has been shown to minimise long-term parking demand while simultaneously increasing airport parking supply. As a result, the airport's revenue was also significantly raised.

A study by Liu (2020) looked at how cost affects the availability of public parking spots. The study determined that increased parking fees would boost government income from parking and buses. In addition, the high parking fees would prevent people from driving their cars and instead encourage them to use public transportation. Parking fees should be at their optimum in order to get the full benefits of this plan.

City planners seek to reduce the number of personal and single-occupant automobiles on the road by imposing a parking fee. In addition to enhancing traffic flow and minimising travel time, these tactics also assist in keeping motorists and other road users safer. Several additional studies have also found that increasing the fleet share of automated vehicles reduces travel time (Atkins, 2016). These studies, however, were conducted taking into account a wide range of parking prices. When passengers have various options for parking, the effects might vary.

3. Methodology

A microsimulation model of Santander city, in Spain was used to investigate the impact of CAVs' parking behaviours (Fig. 1). The network model used has 108 nodes (intersections) and 382 sections (roads). The research analyses the evening hours (19:00-22:00), when leisure and work trips take place, with a traffic flow of 42337 private automobile journeys anticipated.

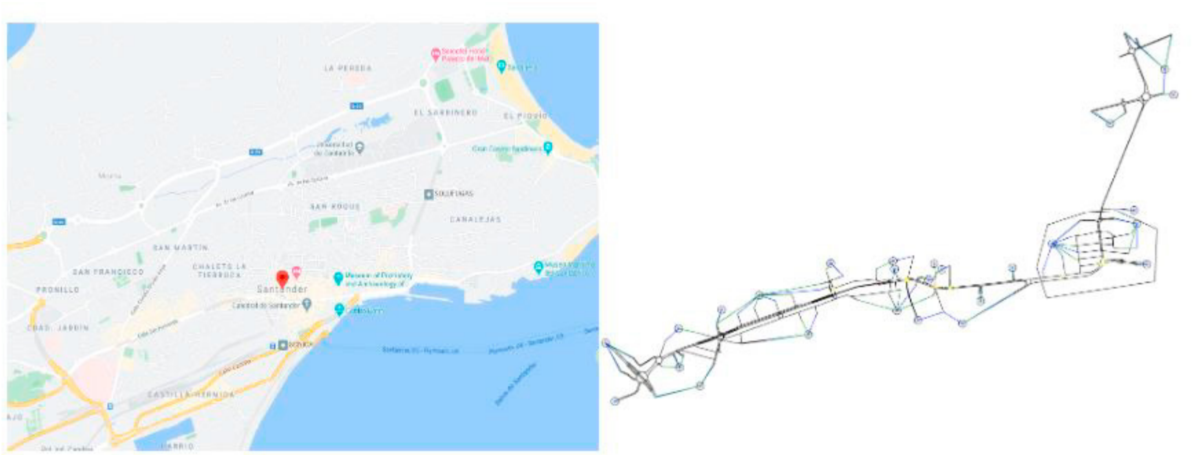


Fig. 1. The modelling area in (a) Santander city and in (b)AIMSUN software.

This study refers to enforcing parking behaviour by varying parking prices. However, these behaviours can also be influenced by limiting total parking spaces within a particular area. With automated vehicles, the widespread belief is that one would be able to command their highly automated vehicles to drive around with no occupants to avoid parking for a short duration. Four parking behaviours were considered for this study (Fig. 2):

- Enter and park inside the area (baseline – consistent with the current situation),
- Enter, drop off passengers and return to origin to park (outside and inside included),
- Enter, drop off passengers and return to the outside parking restriction area to park, and
- Enter and drive around (short stay)

Fig. 2. Parking behaviours

Different scenarios were considered based on the proportions of vehicles choosing these parking options (Table 1). In the baseline scenario, it is assumed that sufficient spaces are available, and vehicles can park themselves inside without causing any disturbance to the traffic. In the 'heavy drive around scenario', vehicles drop the passenger and drive nearby. In the case of 'Heavy Return to origin and Park outside' vehicles do a mixed activity of parking outside and return origin. The 'Balanced' scenario consists of a combination of all the parking choices available.

The proportions of vehicles choosing any of this behaviour was decided with the help of a logit function developed based on the travel cost to reach parking location (seconds) and an assumed varying parking cost at different locations. The proportions of these are given in the following Table 1. Travel time, emissions, delay, and total distance travelled were studied in the present study.

Table 1. Scenarios relating to the prevailing parking behaviours.

Scenarios	Return to Origin	Park Outside	Drive around	Park Inside
Baseline	0%	0%	0%	100%
Case 1 (balanced)	22%	45%	20%	13%
Case 2 (Heavy drive around)	0%	0%	100%	0%
Case 3 (Heavy Return to origin and Park outside)	33%	67%	0%	0%

Regarding CAVs technology, the LEVITATE project considered two types of CAVs: 1st Generation CAVs and 2nd Generation 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. The following are the main assumptions on 1st and 2nd Generation CAV characteristics:

- 1st Generation CAV: 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 Generation CAV: 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 characteristics of both CAV types were defined through various model parameters in AIMSUN Next (Aimsun 2021), including reaction time, time gap, acceleration and deceleration characteristics, parameters related to lane changing and overtaking behaviour and several others. More details on the parametric assumptions and values of key parameters can be found in (Chaudhry et al. 2022).

The deployment of CAVs in the network was evaluated from 0% to 100% in 20% increments (Table 2). The fleet included passenger, freight, and public transport vehicles. Automation was considered for passenger and freight vehicles. Each simulation consisted of ten replications using different random seeds.

Table 2. CAV Deployment Scenarios

Type of Vehicle	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%	--	--	--
1st Generation CAV - passenger vehicle	--	20%	40%	40%	40%	40%	20%	--
2nd Generation CAV -- passenger vehicle	--	--	--	20%	40%	60%	80%	100%
Human-driven - Freight vehicle	100%	80%	40%	--	--	--	--	--
Freight CAV	0%	20%	60%	100%	100%	100%	100%	100%

Assumptions

The following assumptions have been made for this study:

- All CAVs have electric propulsion.
- All human-driven vehicles are non-electric vehicles. These vehicle types use conventional parking destinations.
- CAVs and classic vehicles can travel together without any requirement for dedicated lanes.
- Heavy goods vehicles (HGVs) and large goods vehicles (LGVs) are not considered in the traffic composition.
- Automation and electrification were not considered for public transportation.

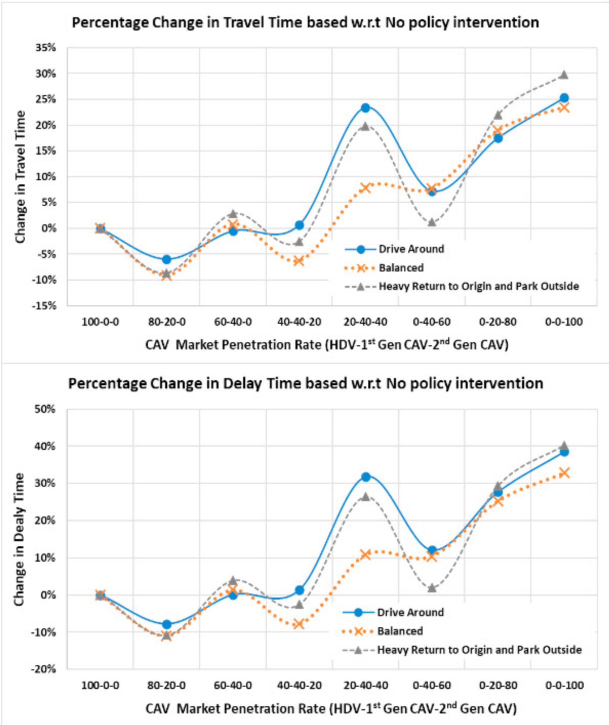
- There exist only the given parking options.

4. Results and discussion

The results obtained from this study have been explained in this section. Results were analysed in two aspects (i) mobility aspects considering travel time, delay, flow and travel time, and (ii) Environmental aspects with – emissions of Particulate Matter-10 (PM), Carbon Dioxide (CO2) and Nitrogen Oxides (NOx) was also considered in the study.

4.1 Mobility aspects

The following graph shows the impact of different parking strategies with respect to (w.r.t.) baseline on various aspects of traffic behaviour, such as delays, flows, and queues (Fig. 3a). Further, it can also be observed that the change in the travel time increases with the market penetration rate (MPR). The maximum increase can be observed in the case of 'heavy return to origin and park outside' (around 30%).

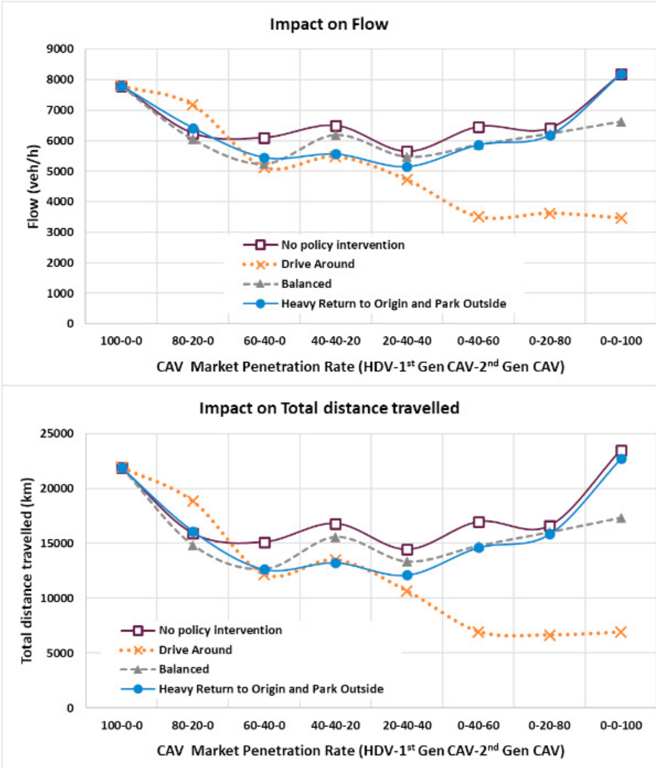


(a)

(b)

Fig. 3. Percent Change in travel time (a) and delay (b) w.r.t to baseline

The trend of delay data can be seen in Fig. 3b. This trend is similar to the trend observed for travel time (Fig. 3a). The delays in the 'balanced' case are the least compared to other scenarios, including 'drive-around' and 'heavy return to origin and park outside'. The reason for this is that in the 'drive-around' scenario, vehicles are never parked, increasing the traffic on the road (Fig. 4a). Hence, the travel time is increased. Similarly, in the case of 'heavy return to origin and park outside', most vehicles use the road and return the parking space leading to increased traffic and travel time. Whereas in the case of the 'balanced' scenario, some of the vehicles (13%) parked inside the centre, leading to a decreased traffic. Hence, the delays are comparatively lower in the 'balanced' scenario.



(a)

(b)

Fig. 4. Impact on traffic flow (a) and total distance travelled (b) with increased MPR of CAVs and parking price policies interventions

The total distance travelled by the vehicles in all the scenarios considered is shown in Fig. 4b. It can be seen that the distance travelled in most of the cases is almost the same (except drive around). However, the distance travelled in the case of 'drive around' decreases with the increment of the market penetration rate. This could be related to the congestion on the roads (Fig. 4a), as vehicles were not allowed to return to the parking spaces, and the volume of traffic increased with the market penetration rate of CAVs.

The change in the travel distance with regards to baseline can be seen in Table 3. The most significant change (up to around 71%) occurs in the case of the 'drive around'. As discussed earlier, the reason for this could be the presence of a heavy volume of traffic on the road. In the remaining CAV parking strategies, this change maintains a small range (from -26.3 to 1.3%).

Table 3. Percent Change in total distance travelled w.r.t corresponding Baseline for various parking policies

Penetration Rate	Drive around	Balanced	Heavy Return to Origin and Park Outside
80-20-0	18,4%	-6,9%	1,3%
60-40-0	-19,5%	-16,4%	-16,4%
40-40-20	-19,6%	-7,3%	-21,2%
20-40-40	-26,2%	-7,6%	-16,1%
0-40-60	-59,0%	-13,0%	-13,9%
0-20-80	-59,9%	-3,5%	-4,6%
0-0-100	-70,6%	-26,3%	-3,4%

4.2 Environmental aspect

The following plot (Fig. 5) shows the effects of CAV penetration rates on tailpipe emissions of CO_2 in different parking strategies. It can be observed that as the penetration of CAVs increases, the emissions reduce drastically. This was consistent in all the different scenarios tested in the study. The major reason for this is the electrification of CAVs considered in the simulation model. Hence, as the proportions of CAVs increase, the emissions are reduced. However, some emissions were observed at the highest market penetration rates caused by conventional public transport.

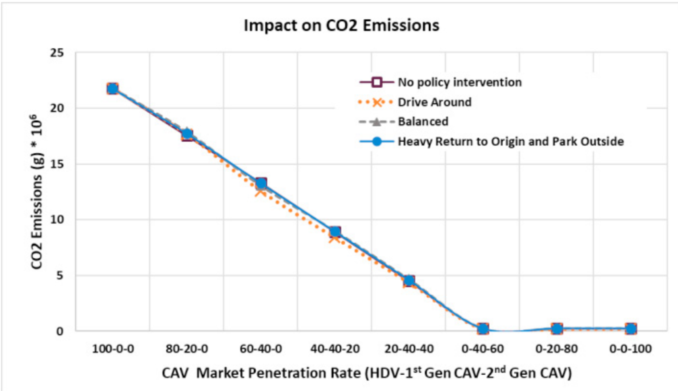


Fig. 5. Impact on CO_2 emissions due to MPR of CAVs and parking price policies interventions

Further, it can be observed from the tables below (Table.4) that the emissions can reduce significantly in the 'drive-around' scenario compared to the baseline. However, it is important to understand that this cannot be considered an advantage because the traffic flow is negatively impacted in the 'drive around' scenario compared to other scenarios (Fig. 4a), making the network congested. The congested network causes a significant reduction of emissions in the 'drive-around' case and should not be considered an improvement. Emissions observed in the full CAVs scenarios (from 0-40-60 to 0-0-100 MPR) were due to background public transport vehicles, which were not considered as electric vehicles in this study.

Table. 4. Change in CO_2, NO_x and PM emissions with respect to the no intervention for parking price policies SUC

MPR	Drive Around			Balanced			Heavy Return to Origin and Park Outside		
	CO_2	NO_x	PM	CO_2	NO_x	PM	CO_2	NOx	PM
80-20-0	1%	-2%	18%	2%	4%	-7%	1%	1%	2%
60-40-0	-5%	-2%	-23%	-2%	2%	-18%	0%	3%	-17%
40-40-20	-6%	-1%	-24%	1%	3%	-8%	0%	6%	-23%
20-40-40	-3%	2%	-29%	3%	6%	-9%	2%	7%	-18%
0-40-60	-14%	4%	-73%	-3%	7%	-21%	0%	6%	-19%
0-20-80	-16%	-2%	-62%	8%	8%	-15%	5%	7%	-15%
0-0-100	-9%	2%	-79%	4%	6%	-34%	9%	4%	-13%

5. Conclusions

Increasing market share of CAVs may change parking behaviour introducing new challenges for city authorities. The mobility and environmental impacts would be dependent on the different driving behaviours and parking strategies of CAVs, e.g., the behaviour for a 1st generation CAV is different from a 2nd generation CAV. The increase of CAVs, which are also electric vehicles, may introduce simultaneous benefits and disbenefits that could be challenging for cities to optimise. Cities have little control over increasing CAV MPR, so they would have to introduce mitigating strategies to avoid the increases in congestion.

Parking restrictions cause extra delays in the system, lower the distance travelled, and have an overall negative influence on the functioning of the network. The 'drive around' scenario of parking behaviour increases the delay by up to 39%. 'Balanced' and 'Heavy Return to Origin and Park Outside' scenarios lead to an increase of 33% and 40%, respectively. These strategies outperformed the 'drive around' strategy. The highest increment in delays was observed in the 'heavy return to origin' (30%) and 'drive around' (25%). It is possible that a 'balanced' parking approach might mitigate the adverse effects of parking fee rules while also encouraging people to use more active modes of transportation. On the other hand, emissions were reduced drastically in all the scenarios with the increment in CAVs share. This happened because all the CAVs were considered electric vehicles.

The advantages that CAVs are highly dependent on parking criteria. Different parking strategies can lead to a fluctuation of 31% in travel time increase. Increasing parking price strategies can have adverse impacts if the proper policy measures are not adopted and implemented.

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