Sustainable Cities and Society 74 (2021) 103152

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

Comparison of intelligent parking guidance system and conventional system with regard to capacity utilisation

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ARTICLE INFO

Keywords:
Intelligent parking guidance system
Capacity utilization of car parks
Car park management
Value of time
Carbon emission

ABSTRACT

The capacity utilisation of car parks is an important issue because of space deficiency for infrastructure improvement in city centres. Intelligent Parking Guidance Systems (IPGSs) provide a solution to such shortages by managing car park capacity. In this study, an IPGS model is proposed concerning the occupancy condition of three surface car parks, and the proposed model is compared with the conventional system (CS) where drivers tend to prefer the closest parking utility. A multi-agent-based simulation program investigates five scenarios and the results compared regarding the occupancy ratio, wasted Value of Time (VoT), and emission of harmful gases. The simulation results illustrate that the proposed IPGS model manages to equilibrate the capacity utilisation of car parks and the parking search period compared with the CS model. Analysis results show that emissions for CS of CO_2, CO, HC, and NO_x are 398.71, 19.90, 3.29, and 21.14 g/s/veh, respectively. This is attributed to the extra search period in the CS models. Besides, the cost of this extra searching period in CS is estimated in terms of the value of time for Turkey, Germany, U.K., and France as 0.49, 0.93, 1.42, and 1.42 euro/veh respectively.

1. Introduction

Car park searching period leads to increase in the time spend in traffic, as well as traffic volume and demand. The traffic congestion arising from this searching period stimulates the traffic delay and this causes to fuel wastage, environmental pollution, and driver aggression. Particularly, the air pollution in the cities is mainly resulting from traffic delay. One method to alleviate pollution related to car park searching period is the car park demand management systems. In the management of the car park demand, informing drivers about car park occupancy have great importance. In this manner, the car park management efficiency increases whereas the searching period decreases.

Intelligent Transportation System (ITS) is a prevalent demand management method for increasing traffic demand in developed cities for sustainability. Nowadays, the most commonly discussed issue in ITSs is the vehicle-routing issue, especially in the parking place-searching process. IPGSs are implemented in many developed cities to deal with the time elapsed in the parking place-searching process and manage existing parking facilities efficiently. To do this, IPGSs produce guidance information concerning real-time data to support the parking place searching period. In the process of guidance, IPGSs use sensor systems and telecommunication networks to remote real-time monitoring, data collection, produce individual parking guidance assistance for each driver and provide graphical guidance interface (Shin, Jun & Kim, 2018). Those technologies extinguish human errors, especially in data collection (Abdulrahman, Almusawi & Abubakar, 2017).

The parking behaviour of the drivers is the consequence of a complicated interaction process between the individual characteristics and parking opportunities. Drivers accept various approaches based on the previous parking search experiences and the operation of the transportation system. The parking behaviour of drivers is still undetermined precisely owing to the complexity inherent of the parking choice process (Guo, Huang, Zhuang & Sadek, 2013). It is challenging to manage car park demand in CSs due to this complexity. To deal with this difficulty, IPGSs are implemented to the parking system for efficient management of the parking demand.

One of the main purposes of the IPGSs is the effective capacity utilisation of car parks in consideration of the collected data and the parking behaviour of the drivers. In previous studies, capacity utilisation of car parks is attempted to benchmark by various methods. Those methods regard different indicators of preference for the car parks such as occupancy, driving distance, walking distance, parking cost, traffic

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https://doi.org/10.1016/j.scs.2021.103152
Received 30 November 2020; Received in revised form 24 May 2021; Accepted 30 June 2021
Available online 17 July 2021
2210-6707/

Table 1
Studies on the effect of IPGs on capacity utilisation of the car park.

Studies	System	Guidance based on	Method	Improvement
(Boltze & Puzicha, 1995)	PGS	Occupancy	Survey	Capacity utilization Queue length Searching time
(Thompson, Takada & Kobayakawa, 2001)	PGS	Occupancy	Mathematical programme	Queue length Travel distance
(Wendi, 2009)	PGS	Ad hoc On-Demand Distance Vector (AODV) routing protocol	Simulation	Capacity utilization Information reliability Travel time
(J. Shin & Jun, 2014)	IPGS	Occupancy Parking cost Driving Distance Walking distance Traffic congestion	Simulation	Travel time Capacity utilisation Walking distance Fail Park
(J. H. Shin et al., 2018)	IPGS	Occupancy Parking cost Driving Distance Walking distance Traffic congestion	Simulation	Travel time Capacity utilisation Walking distance Traffic congestion
(Qamar, 2019)	PGS	Selective parking discovery algorithm	Simulation	Travel time Capacity utilisation
(Dogaroglu & Caliskanelli, 2020)	IPGS	Occupancy Parking cost Driving Distance Walking distance Traffic congestion	Multi-Agent Based Simulation	Travel time Parking cost Walking distance CO_2 Emission
In this study	IPGS	Search period in car park Occupancy Driving Distance	Multi-Agent Based Simulation	Capacity utilisation CO_2, CO, HC, and NO_x Emissions VoT

congestion, etc. given in Table 1. This study is included in Table 1 additionally to emphasize the distinctness of the applied method and evaluation methods regarding previous studies. In contrast to previous studies, the advantage of IPGSs is evaluated regarding parking search time in the car park and the benefits are assessed considering VoT and emission of harmful gases in this study.

The study aims to investigate the effects of IPGS on parking preferences to enhance the efficiency of car parks in terms of capacity utilisation. Accordingly, this study has two main contributions to the area. The first one is the model combination. In literature, most of the studies conducted are based on two models, either the on-trip/pre-trip car park preferences or preference inside the car park. On-trip/pre-trip car park preference is not related to parking space searching time inside the car park. However, parking place search time has a distinct effect on fuel consumption, harmful gas emissions, and loss of time. The novelty of the study is the investigation of the interaction of those two preference models considering the loss of time arising the parking place search period inside the car parks. Furthermore, the effect of intelligent on-trip/pre-trip guidance on inside parking place search time is evaluated utilising a multi-agent intelligent parking guidance simulation system. The second contribution of the study is that obtained results are analysed based on the VoT and emission of the harmful gases. Moreover, this study presents a VoT parameter to assess the cost of the project in the design and the construction of the infrastructure. For this purpose, five scenarios for two models are presented and simulated by the previously created multi-agent-based simulation program in NetLogo (Dogaroglu, 2019; Dogaroglu & Caliskanelli, 2020). In the first model, the CS is simulated where the drivers choose one of three car parks via the driving distances. In the second model, an IPGS model is simulated that directs the drivers toward one of three car parks considering the occupancy. The simulation results of these two models are compared in terms of capacity utilisation of car parks. In CS model, as the drivers are not informed about occupancy, extra in-park search time occurs after the closest car park reaches capacity. This extra in-park search time is calculated and evaluated in terms of VoT and emission of pollutant gases.

The rest of the paper is separated into five sections after the introduction part. In the second section of this paper following up on the introduction section, a literature review is presented that is related to the content of the study. The third section highlights the background of the study. In the fourth section, the methodology of the study is outlined through the scenarios designated. Results of the simulated scenarios and analysis are given in the fifth section. The paper ends with a brief discussion in the conclusion section.

2. Literature review

As the number of cars on roads grows and the number of parking spaces is reduced, traffic congestion is unavoidable. Such congestion, as well as environmental pollution, would contribute to driver violence. It is a difficult task to recognize these challenges and attempt to address them in a way that is productive and sustainable at the same time. One of the reasons for moving into a smart city environment is to take advantage of the ability of current technology and infrastructures to provide people with the highest possible utility and enhance their future.

The process of IPGS depends on the car park assignment that deals with the parking preference behaviour of drivers. Agent-based and multi-agent based simulations are the most prevalent method used in previous studies on car park preferences. For instance, to model off-street parking drivers' behaviour, Bonsall and Palmer (2004) developed a car park preference simulation in PARKIT. Similarly, Benenson, Martens and Birfir (2008) used PARKAGENT, which is an agent-based model, to determine on-street parking drives' behaviour in Tel Aviv. Also, Chou, Lin and Li (2008) proposed an intelligent agent-based system to guide drivers to the optimal car park.

In the optimisation process, the proposed system considers preference parameters such as parking fees, driving distance, reservation policies, and available parking spaces. Bilal, Persson, Ramparany, Picard and Boissier (2012) developed a multi-agent model included in the platform SensCity that is a machine-to-machine (M2M) system. The model considers parking area location, hourly price, properties of parking place, maximum-parking duration, and availability in car park preferences. Dieussaert, Aerts, Steenberghen, Maerivoet and Spitaels (2009) created an agent-based model, entitled SUSTAPARK, for modelling traffic caused by parking search, based on evaluation time, exploration time, egress time, and parking fee. More recently, in their study, Di Napoli, Di Nocera and Rossi (2014) mentioned that parking utilisation is a mechanism based on a negotiation between parking place vendors and inquirers. They proposed a model regarding parking location, cost, availability, and the distance of a car park from the city centre. Zhao, Li, Wang, Li and Du (2018) offered a bi-level method with different user classes and various forms of parking spaces in a large car park. The upper level of the proposed model object to enhances the cost in the searching period and walking time. In the lower level, they create a multi-agent simulation system in NetLogo to describe driver response

Table 2
Studies on parking detection sensors.

	Sensors	Literature	Intrusive	Flexible	Environmental Impact	Small Size	Privacy	Multiple Detection
Stationary	Active / Passive infrared	(Larisis, Perlepes, Kikiras & Stamoulis, 2012; Männi, 2010; Moguel, Preciado & Preciado, 2014; Perković, Šolić, Zargariasl, Čoko & Rodrigues, 2020)		✓	✓	✓		✓
	Accelerator	(H. Wang & He, 2011)			✓	✓		✓
	Magnetometre	(Boda, Nasipuri & Howitt, 2007; Chien, Chen & Lin, 2020; Floris, Girau, Porcu, Pettorru & Atzori, 2020; Yoo et al., 2008; W. C. Zhao, 2012)	✓			✓		
	Ultrasonic	(Elsonbaty, 2020; Kianpisheh, Mustaffa, Limtrairut & Keikhosrokiani, 2012)		✓	✓	✓	✓	✓
	Camera	(Al-Turjman & Malekloo, 2020; Bin, Dalin, Fang & Tingting, 2009; Bulan et al., 2013; Sevillano, Màrmol & Fernandez-Arguedas, 2014)		✓	✓	✓	✓	✓
	Acoustic	(Al-Turjman & Malekloo, 2019, 2020; Lee, Yoon & Ghosh, 2008; Na, Kim & Cha, 2009)		✓	✓	✓	✓	✓
	Optical	(Athira, Lekshmi, Vijayan & Kurian, 2019; Chinrungrueng, Sunantachaikul & Triamlumlerd, 2007; Lee et al., 2008; Samann & others, 2020)		✓	✓	✓		
	Inductive loop	(Al-Turjman & Malekloo, 2019, 2020; David, Overkamp & Scheuerer, 2000; Kianpisheh et al., 2012; Sarangi, Das & Babu, 2019)	✓					
	Piezoelectric sensor	(Al-Turjman & Malekloo, 2019, 2020; Perković et al., 2020; Yan, Yang, Rawat & Olariu, 2011)	✓		✓			✓
	RFID	(Al-Turjman & Malekloo, 2019, 2020; Al Taweel, Challagundla, Pagan & Abuzneid, 2020; Djenouri, Karbab, Boulkaboul & Bagula, 2015; Y. Liu, Zou, Shi & Zhuang, 2012)	✓	✓		✓	✓	
	Radar	(Cai, Zhou, Qi, Zhuang & Deng, 2020; Perković et al., 2020)		✓	✓	✓		
Mobile	Ultrasonic	(Coric & Gruteser, 2013; Mathur et al., 2010)		✓	✓	✓		✓
	Laser rangefinder	(Gong et al., 2019; Jung, Cho, Yoon & Kim, 2008)		✓	✓	✓		✓
	Smartphone	(Bechini, Marcelloni & Segatori, 2014; Koster, Oliveira, Volpato, Delvequio & Koch, 2014; Stenneth, Wolfson, Xu & Philip, 2012)		✓	✓	✓	✓	✓
	Camera	(Abdul Halim Sithiq, B., Rahman & Limnardy, 2019; Luque-Vega, Michel-Torres, Lopez-Neri, Carlos-Mancilla & González-Jiménez, 2020; Petsch, Dotzlaf, Daubenspeck, Duthie & Mock, 2012)		✓	✓	✓	✓	✓

and movement concerning various management strategies. In the study, they surveyed travel time, walking distance, and the probability of parking to determine drivers' preferences in Shanghai, China. A simulated annealing algorithm was adjusted to the optimisation process of the bi-level simulation. The model was used to optimise parking management at Tongji University, China. They determined that different time intervals are beneficial to adjust the time-varying demand for various user classes.

Both the drivers and the operator benefit from IPGS. To locate the closest parking spaces, drivers use IPGS whereas, the parking managers will use the system to gather details for better negotiations on parking place trends and pricing plans. IPGS provides many appealing facilities, such as smart payment and/or reservation, which can greatly boost the experience of both drivers and operators. IPGS architectures typically consist of many layers dependant on their functionality (Bagula, Castelli & Zennaro, 2015; Revathi & Dhulipala, 2012).

First, the sensor layer, which is the backbone of the smart parking system is responsible for detecting the presence and/or absence of a vehicle using various sensor technologies in an environment. Receivers, transmitters, and anchors are often composed of these technologies (Al-Turjman & Malekloo, 2019). The summary of related studies is given in Table 2.

Second, the organization layer, and it is the correspondence fragment of the framework, which is liable for trading messages between transmitters/collectors and the anchors. Thirdly, the IPGS processing layer is the middleware applications in which refined and intelligent calculations are used to deal with the real-time information. It also serves as a store of information, as well as a communication between end-users seeking services from the lower layers. Finally, the device layer, which is the top layer of the system, interfaces the IPGS with customers requesting various services from separate mobile and/or stationary information panels. It is possible to categorize these multi-layered parking systems into the three categories given in Table 3.

3. Background

This part of the paper is related to the notions in this paper, including IPGSs, multi-agent-based software NetLogo, studies on the value of time, and road vehicle emission models.

3.1. Multi-agent-based software NetLogo

NetLogo is an open access, multi-agent-based software that was produced at the Centre for Connected Learning and Computer-Based Modelling (CCL) at Northwestern University, directed by Uri Wilensky (Sklar, 2007). As a multi-agent-based modelling simulation environment, NetLogo has advantages for simulation of behaviours of agents amongst various micro-simulation programs (Chen, Xu, Zangui & Yin, 2016; Vo, van der Waerden & Wets, 2016). NetLogo is a modest and prevailing open-source software, and it provides a model creation environment to assist the user to develop their simulation program (Tisue & Wilensky, 2004). For instance, Vo et al. (2016)developed a micro-simulation for movements of drivers at the car park via the NetLogo environment. Z. Chen et al. (2016) proposed a model to examine search behaviours of drivers for parking. In their model, on-street parking spaces are dispersed around the destination. Drivers are supposed to accept a parking space concerning the minimum walking time. An agent-based simulation model in NetLogo is developed to verify the results of the prediction gathered from the analytical models.

Table 3
Categorization of smart parking systems.

IPGS	Sub-Systems	Specification	Related works
Centralised assisted IPGS	Parking guidance and information system	Gather car park information dynamically from loop detectors, ultrasonic, infrared, and microwave sensors to apprise the motorists in real-time manners about the situation of the parking lot through a guidance system or variable message signs (VMS).	(Dogaroglu, 2019; Dogaroglu & Caliskanelli, 2020; J. Liu, Wu & Sun, 2020; Patil & Bhonge, 2013; Qian & Hongyan, 2015)
	Centralised assisted parking search	The first client vehicle is directed toward a certain available spot nearby to the driver location (the First Come First Serve approach). However, in this method, the other vehicles in the line are in nonstop movement until the server satisfy them. This contributes to the problem of uncooperability between drivers that can dramatically reduce centralised assisted parking search efficiency. Additionally, Centralised assisted parking search is still deeply worried about the high cost of upkeep and scalability.	(Al-Turjman & Malekloo, 2019, 2020; Kokolaki, Karaliopoulos & Stavrakakis, 2012; Raichura & Padhariya, 2014; Revathi & Dhulipala, 2012)
	Car park occupancy information system	To detect the presence and/or absence of cars, car park occupancy information system uses video sensor techniques based on a single source. On information panels that are strategically located around the car park, the condition is then posted. The reliance of Car park occupancy information system is primarily on four technologies: the counter-based technology, the wired sensor-based technology, the wireless sensor-based technology, and the computer-vision based technology. Knowing that without deploying other sensors in each spot, using the new technologies will produce more precise results regarding the exact state of the parking spot.	(Al-Turjman & Malekloo, 2019; Dieussaert et al., 2009; Dogaroglu, 2019; Dogaroglu & Caliskanelli, 2020)
	Agent based guiding system	Simulates each driver's behaviour in a diverse and complex environment. In this framework, the agent can make choices and identify the relationship between the driver and the parking system on the basis of perceived driver facts and other factors that differ, such as reactivity, autonomy, proactivity, adaptability and social power.	(Benenson et al., 2008; Chou et al., 2008; Diaz Dieussaert et al., 2009; Dogaroglu, 2019; Dogaroglu & Caliskanelli, 2020; Mei, Zhang, Zhang & Wang, 2020; Ogás, G., Fabregat & Aciar, 2020)
	Automated parking	Consists of mechanical systems that are computer-controlled that enable drivers to move their cars into a specified bay and allow the rest of the work to be managed by the automated parking system.	(Buntić, Ivanjko & Gold, 2012; Chinrungrueng et al., 2007; Hassan, Islam, Fahim, Turja & Chowdhury, 2020; Hattori, 2020; Idris, Leng, Tamil, Noor & Razak, 2009; Wu, Xu & Lu, 2020)
Distributed assisted IPS	Transit based information system	Transit based information system is a guidance system focused on park and ride with related functionalities to parking guidance and information system. To steer them into a vacant parking space, it interacts with drivers via variable massage system (VMS). It also offers real-time updates on the state of public transit schedules/ routes, enabling drivers to more accurately prepare their journey beforehand.	(Horner & Groves, 2007; Krishnamurthy & Ngo, 2020; Pal & Singh, 2011; Rodier & Shaheen, 2010)
	Opportunistically assisted parking search	Share details about the parking spots' condition and location. This allows drivers, while they search in the crowd to make more knowledgeable decisions. In this approach, by evaluating timestamps and geographical addresses using GPS	(Al-Turjman & Malekloo, 2018; Kokolaki et al., 2012, 2013)

(continued on next page)

Table 3 (*continued*)

IPGS	Sub-Systems	Specification	Related works
		units, drivers are guided toward the closest vacant parking space.	
Utilisation in practice	Smart payment system	With Internet of Things (IoT) and advanced technology that ensures reliability and fast payment methods, the smart payment system has been developed and integrated. To fulfil its function, this device utilises contact, contactless, and mobile modes. Smart cards and Radio Frequency Identification (RFID) technology such as Automatic Vehicle Identification (AVI) tags are used in a contactless mode. Credit and debit cards are used in contact mode. Mobile telephony systems are used in the mobile mode to receive payments.	(Al-Turjman & Malekloo, 2018; Čuljković, 2018; Revathi & Dhulipala, 2012; Shi, Jin, Li & Fang, 2017; Yu, Ng, Liong & Hanafi, 2020)
	Parking reservation system	In specific, parking reservation system (PRS) helps drivers secure a parking space at peak hours or during their journey. The aim of parking reservation system is to either increase the income from parking or minimize the fee for parking. Various components are needed to incorporate the PRS: the reservation information centre, the communication mechanism between users and the parking reservation system, the real-time car park-monitoring system, and the calculation of the planned demands.	(Barakian, 2020; Boudali & Ouada, 2017; Marizalee, 2020; Mei et al., 2020; Ni & Sun, 2017; Thangam, Mohan, Ganesh & Sukesh, 2018)
	E-parking system	E-parking system offers a framework through which consumers can receive information electronically from other systems and sensors about the actual vacancy of car parks. Additionally, without leaving the car and before entering the parking lot, reservations and payments are made all in one go. It is possible to access the system through mobile phones or web-based apps. A confirmation code is sent via SMS to the user's email and/or cell phone to identify the vehicle making reservations, which can then be used to verify the vehicle's identity.	(Mahendra, Sonoli, Bhat & Raghu, 2017; RANJAN & MISHRA, 2018; Sadhukhan, 2017; SOEGOTO & SUPRIANTI, 2019)

3.2. Value of time

VoT or, more specifically, values of travel time savings (VTTS) are the main concepts in cost-benefit analysis (CBA) of transport. VoT denotes the value of a reduction in the time elapsed by a specific journey. It depends on the reliability of the cruise period, the comfort, and other particular features of the journey. These factors affect the perceived value of time elapsed, the opportunities and possibilities of using the travel time for other events, and the utility during travel (Meunier, 2020).

Various studies have been conducted to determine VoT in transport, particularly for regions, cities, or countries. X. M. Chen, Liu and Du (2011) analysed factors that affect transit values of travel time with survey data in Beijing. They used a Logit-based model and proposed an enhanced survey-based model in which the revenue of passengers is taken into consideration as a variable. The study showed that work-based travel time values are mostly higher than leisure-based travel time values. Moreover, they found that the values of waiting time are greater than the values of transferring time and values of in-vehicle time in all conditions. Meunier and Quinet (2015) investigated and considered the recommendations of the French government report, in the structure of a general CBA, regarding the value of time. Meunier, Walther, Worsley, Dahl and Le Maître (2016) determined, examined and evaluated the development of reference values in national guidelines provided for infrastructure projects CBA of transport, since fifty years, in France, UK, and Germany.

3.3. Road vehicles emission models (RVEMs)

One of the main hazards to health and the environment is air pollution. Thus, authorities must accurately predict contaminative emissions for appropriately designed and implemented air quality plans (Shen et al., 2020). There are many parameters that road vehicle emissions depend on. Various emission models are used in the assessment of road vehicle emissions (Franco et al., 2013). Cappiello, Chabini, Nam, Lue and Abou Zeid (2002) established an instantaneous emission model for CO_2, CO, HC, and NO_x and fuel consumption for light-duty vehicles. The proposed model can assess the impact of ITS strategies on travel times, emissions, and fuel consumption. Smit, Ntziachristos and Boulter (2010) defined the emission RVEMs in 5 groups; the average-speed model, Traffic-situation models, Traffic-variable models, Cycle-variable models, and Modal models. Wang, Szeto, Han and Friesz (2018), on the other hand, used the taxonomy for vehicle emission modelling, namely, static and dynamic modelling. Aggregated models (AGO, 2007; NAEI, 2012), average-speed models (Boulter, McCrae & Barlow, 2007; Ntziachristos et al., 2000), traffic situation models (Boulter & McCrae, 2007; Keller & de Haan, 2004) are defined as subtitles under static modelling. Moreover, regression-based models (Ahn, Rakha, Trani & Van Aerde, 2002; Smit, Smokers & Rabé, 2007), modal

Table 4
Types of emission models.

The main type of model	Subtype of models	Unit of Emission Factor (EF)	EF type	Vehicle-related input
Static	Aggregated	g/VKT, g/VMT, g/L	Discrete	Fuel scales
	Average-speed	g/VKT, g/VMT	Continuous	Vehicle type
	Traffic situation	g/VKT, g/VMT	Discrete	Vehicle type
Dynamic	Regression	g/s or g/VKT, g/VMT	Continuous/discrete	Vehicle type
	Modal	g/s or g/VKT, g/VMT	Discrete	Vehicle characteristics
	Instantaneous	g/s	Discrete	Vehicle characteristics

Table 5
Model definitions.

Model	Definition	Guidance	Driver Preference
M1	Conventional System	Drivers' Perception	Distance
M2	IPGS	Intelligent Guidance	Occupancy Condition

models (Fomunung, Washington & Guensler, 1999), and instantaneous models (Hausberger, Rodler, Sturm & Rexeis, 2003; Scora & Barth, 2006) are classified under dynamic modelling. An overview of defined emission taxonomy is illustrated in Table 4 which is created refer to the study of Wang et al. (2018).

4. Methodology

In the study, two models are presented to determine the effect of IPGS on parking preferences and car park utilisation. The first model, M1, is denoted as a conventional system in which the drivers prefer the closest car park in their route. The second model, M2, is an IPGS, which is managing the parking demand according to the occupancy condition and capacity usage of the car parks. The explanation of models is briefly given in Table 5.

4.1. Simulation program

In this study, a previously developed simulation software by using NetLogo is used to evaluate the capacity utilisation of car parks regarding various scenarios prepared according to fair acceptances (Dogaroglu, 2019; Dogaroglu & Caliskanelli, 2020).

The interface of the created simulation program is given in Fig. 1. The simulation program is developed for a more comprehensive study on the parking preference. In the program, agents are directed to three car parks considering a utility function composed of five parameters that are driving distance, walking distance, cost, traffic, and car park availability. For this study, driving distance and availability of car parks are taken into consideration in simulations for M1 and M2, respectively.

In M1, drivers (agents) are directed to the closest car park whereas, in M2, agents are guided to the most convenient car park concerning the occupancy based on instantaneous calculations of the degree of availability by Eq. (1) and 2 (J. Shin & Jun, 2014).

$$R_{ij} = \frac{\frac{T_{ij}}{MTBA_j}}{f_j} \tag{1}$$

Where;

$MTBA_j$ is the mean time between the vehicle arrivals at car park j ($j = 1,\ldots, m$);
R_{ij} is the degree of availability of car park j for the i^{th} vehicle;
T_{ij} is the total arrival time of the i^{th} vehicle for car park j;

f_i is the number of free parking places in car park j at *a certain time, t.*
Eq. (2) is used to calculate *the mean time between car arrivals ($MTBA_j$)* in the simulation program.

$$MTBA_j = \frac{\sum_{k=2}^{q_j}\left(t_{jk} - t_{j(k-1)}\right)}{q_j - 1} \tag{2}$$

Where;

k is the vehicle arrival index at a specific time interval for car park j ($k = 1,\ldots, q_j$);
t_{jk} is the k^{th} car arrival time at car park j ($j = 1,\ldots, m$);
q_j is the number of cars that arrive in the car park j at a certain period ($j = 1,\ldots, m$).

The validity of the created simulation software has been proven in previous studies (Dogaroglu, 2019; Dogaroglu & Caliskanelli, 2020). For the validity of the software, real data were collected by observing 3 car parks in Izmir- Turkey. In the validation process, the software is used to simulate similar conditions, and acquired data from the simulation are compared with the observed data based on various statistical methods that are the discrepancy ratio (DR), root mean square error (RMSE), efficiency factor (EF), and regression analysis. All statistical evaluations

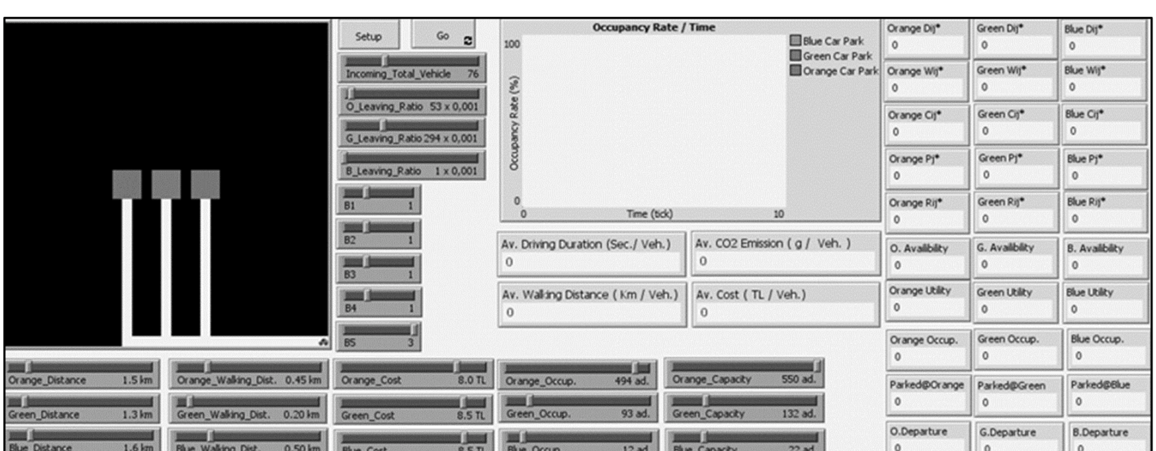

Fig. 1. IPGS simulation program created in NetLogo.

Table 6
Calibrated parameters for CO_2 emission (Cappiello et al., 2002).

A	1.11
B	0.0134
C	1.98E-06
D	0.241

Table 7
Calibrated parameters for CO, HC, and NO_x emission (Cappiello et al., 2002).

	CO	HC	NO_X
A	0.0316	0.00916	−0.00391
B	dropped	dropped	0.000305
C	1.09E-07	7.55E-09	2.27E-08
D	0.00883	0.00111	0.00307

Table 8
The catalyst pass fractions (Cappiello et al., 2002),.

CPF_i	Equation	if
$CPF_{CO} =$	0	$EO_{co} < 0.005$
	$1.15 * EO_{co} - 0.006$	$0.005 < EO_{co} < 0.705$
	$0.045 * EO_{co} + 0.746$	$0.705 < EO_{co}$
$CPF_{HC} =$	0.0011	$EO_{HC} < 0.011$
	$3.69 * EO_{HC} - 0.031$	$0.011 < EO_{HC} < 0.047$
	$23.39 * EO_{HC} - 0.977$	$0.047 < EO_{HC}$
$CPF_{NOx} =$	$0.124 * EO_{NOx} + 0.067$	

determine that the simulation software properly estimates the data observed (please refer to studies by Dogaroglu, 2019; Dogaroglu & Caliskanelli, 2020).

4.2. Tailpipe emission

In the evaluation of the extra time elapsed in full car parks, the tailpipe emissions of the vehicle are calculated to determine excessive pollutant gases occur. One of the models developed for tailpipe emission in the literature is used to calculate the CO_2, CO, HC, and NO_x emissions (Cappiello et al., 2002). In this study, they proposed a model to calculate CO_2 emission given in Eq.(3).

$$TP_{CO_2} = A_{CO_2} + B_{CO_2} v + C_{CO_2} v^3 + D_{CO_2} av \quad (3)$$

Where;

TP_{CO_2}: tailpipe emission rate (g/s)
v: vehicle speed (km/h)
av: speed times acceleration (m^2/s^3)

Table 9
Simulation Input Values.

Scenario	Car Park (C.P.) Startup Occup.			Total arrival (veh.)
	1st C.P.	2nd C.P.	3rd C.P.	
1st	0	0	0	700
2nd	225	0	0	550
3rd	100	100	100	450
4th	175	150	125	250
5th	125	150	175	250

A, B, C, D: calibrated parameters.

Calibrated parameters for CO_2 emission are given in Table 6.

For calculating of CO, HC, and NO_x, Cappiello et al. (2002) propose a generalised model given in Eq.(4) where EO_i denotes the engine-out emission rate of species i in g/s and CPF_i denotes the catalyst pass fraction for species i.

$$TP_i = EO_i * CPF_i \quad (4)$$

To calculate EO_i, Eq. (5) is used for all CO, HC, and NO_x emissions.

$$EO_i = A_i + B_i v + C_i v^3 + D_i av \quad (5)$$

Calibrated parameters for CO, HC, and NO_x emission are given in Table 7.

The catalyst pass fractions (CPF_i) for CO, HC, and NO_x are calculated with the piecewise linear functions given in Table 8.

4.3. Scenarios

In the simulations, drivers are guided to three car parks, which have different driving distances from the starting point of the cruise that is 1.00, 1.50, and 2.00 km, respectively. The capacity of the car parks is accepted as 275 units. In each scenario, the start-up occupancy of the car parks is considered variable and all scenarios are simulated for both M1 and M2. Moreover, it is assumed that no vehicles leave car parks during the simulations. In M1, there is no information or warning sign around the car parks showing the occupancy or capacity of the car parks. In M2, drivers are considered that they all use IPGS in their cruise to car parks and abide by the guidance of IPGS. Fig. 2 illustrates the car parks and cruise direction.

For this study, five scenarios are simulated with different startup occupancies and vehicle-arrival numbers in order to create a different combination of occupancy occasion, given in Table 9. In the first simulation, startup occupancies for all car parks are accepted as 0. The main purpose of the 1st scenario is to detect the effects of IPGS for similar conditions with CS in terms of occupancy ratio. For the second scenario, startup occupancy of the 1st car park, the closest one, is designated as 225 units, which is an approximate value to its capacity. The second scenario aims to determines the disutility of CS, where the closest car park is preferred. In the third simulation, startup occupancy is

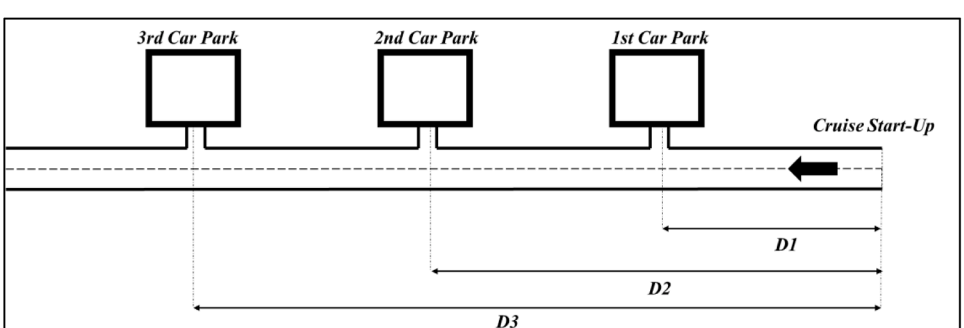

Fig. 2. Illustration of the Three Car Park Scenario (D1:1.00 km; D2:1.50 km; D3:2.00 km).

Table 10
Arrival and departure rates with simulation periods for Poisson process.

Scenario	Arrival Rate (veh/s)	Departure Rate (veh/s)	Arrival (veh)	Total Time (sn)	Total Tick
1st	0.326797386	0.025	700	2142	714
2nd	0.326797386	0.025	550	1683	561
3rd	0.326797386	0.025	450	1377	459
4th	0.326797386	0.025	250	765	255
5th	0.326797386	0.025	250	765	255

designated as 100 units for all car parks. The difference between the first simulation and the third one is the vehicle-arrival numbers. In the third simulation, the arrival number is selected as 450 units, which are approximately equal to free parking places (525 units) at the startup. In the fourth simulation, slightly different startup occupancy ratios of car parks are chosen where the 3rd one is the lowest, and the 1st one is the highest. Conversely, in the fifth simulation, the first startup occupancy ratio is the lowest, and the third one is the highest.

All simulation scenarios are executed considering two situations:

1 *Randomly arrivals with no departure:* In the defined scenarios in table 9, vehicle arrivals for car park search are generated randomly and there is no departure from car parks in the simulation time periods.
2 *Poisson arrivals with departure:* In the literature, there are two arrival types for car park simulations. One is a random or arbitrary type of arrival (Ni & Sun, 2017; Sana, Riadh & Rafaa, 2014; J. Shin & Jun, 2014; Tilahun & Di Marzo Serugendo, 2017; Vo et al., 2016) and the other is the Poisson process (Geng & Cassandras, 2013; Klappenecker, Lee & Welch, 2014; Sun, Ni & Zhang, 2016; Xu, Zhang, Wan & Li, 2014). In the study, to illustrate whether the arrival randomness has any effect or not, the Poisson process is applied and results are compared with the random arrival type. Poisson arrival rate is denoted as λ_1=1000/3060 car per second (Klappenecker et al., 2014). Furthermore, departure rate is applied to the simulation to detect whether it has any effect on the occupancy rate of car parks. The departure rate is accepted as λ_2=0.025 car per second (Xu et al., 2014). The arrival and departure rates with simulation time are given in Table10. In the table, simulation time is denoted as Tick as presented in Netlogo. In the created simulation program, 1 tick period is adjusted to 3 s. Based on this, time periods are illustrated in Table 10 both in tick and second.

5. Analysis and results

5.1. Capacity utilisation results

The results of simulations are shown in an occupancy versus time graphs, given in Figs. 3-7. In those figures, the occupancy ratio refers to capacity usage of car parks and is assessed by dividing the number of the parked vehicles by car park capacity.

Results show that for all scenarios, IPGS equilibrate the capacity usage of all car parks in comparison to the CS. Moreover, drivers tend to fill up the first car park in the CS, whereas an equilibrium state occurs at all car parks in IPGS. In Fig. 3, graph lines synchronise with each other, and none of the car parks reach capacity at IPGS. However, in the CS, first and second car parks reach capacity, respectively, whereas the capacity utilisation of the third one remains 55%. In Figs. 4-6, the first car park reaches capacity rapidly, and the second one reaches capacity subsequently in the CS. However, in IPGS, the occupancy ratio of three car parks increases together in an equilibrium condition. In Fig. 7, a similar condition occurs according to the occupancy ratio, but the 2nd car park does not reach capacity, and none of the drivers prefer 3rd car park in the CS. However, IPGS results show more balanced capacity utilisation.

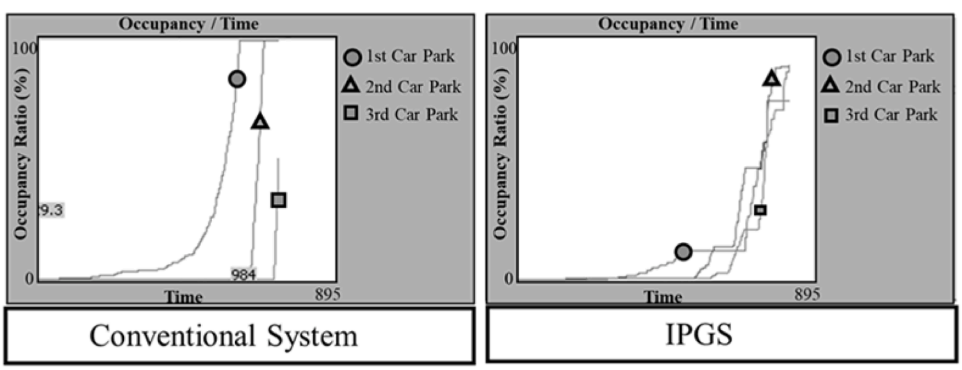

Fig. 3. 1st Simulation Results in comparison with Conventional System and IPGS.

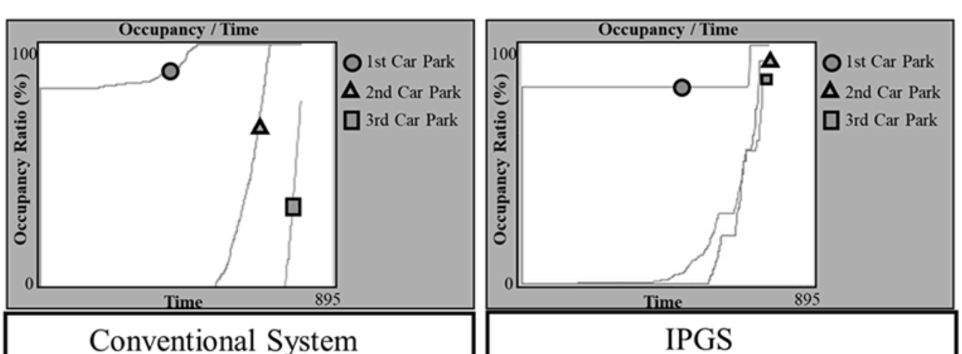

Fig. 4. 2nd Simulation Results in compared with Conventional System and IPGS.

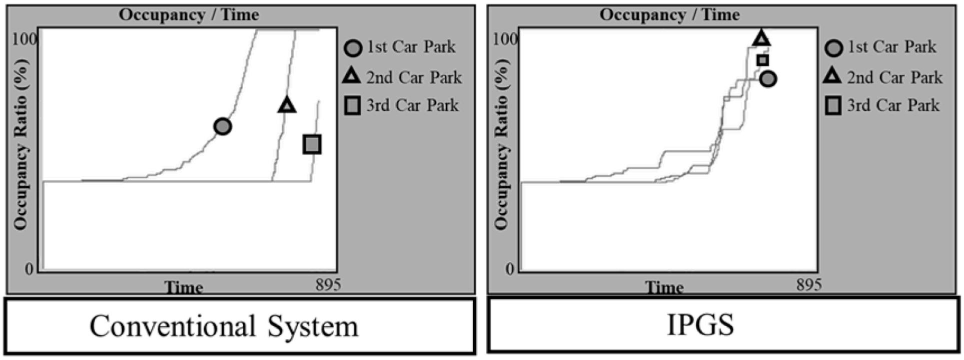

Fig. 5. 3rd Simulation Results in compared with Conventional System and IPGS.

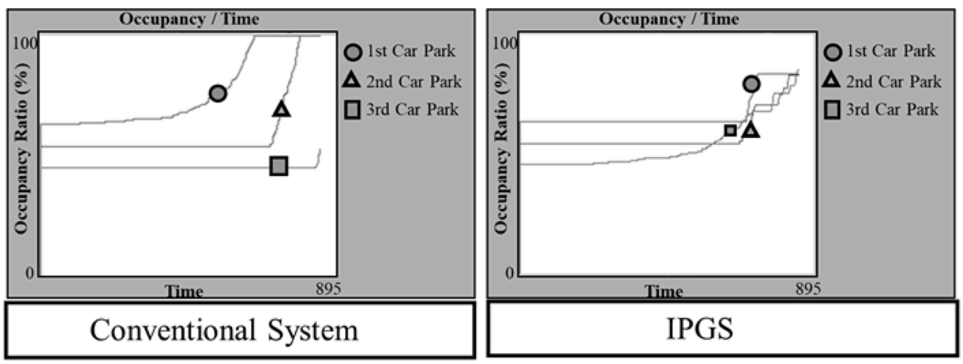

Fig. 6. 4th Simulation Results in compared with Conventional System and IPGS.

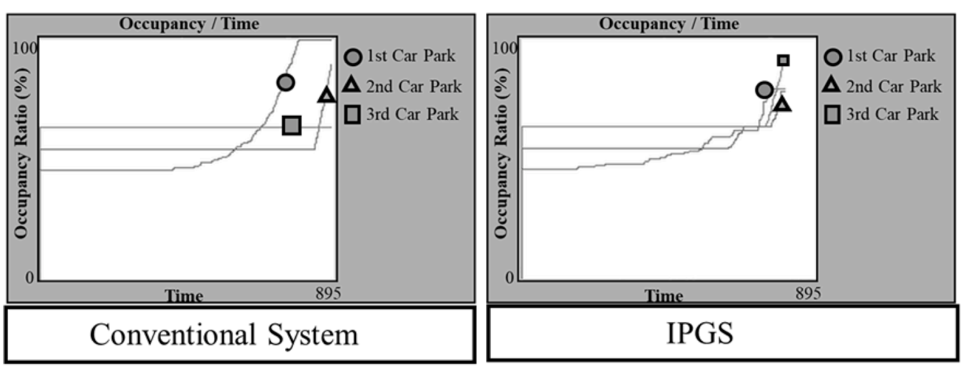

Fig. 7. 5th Simulation Results in compared with Conventional System and IPGS.

The results of the Poisson process with departure rates are given in Fig. 8. The graphs illustrate that in CS models, the occupancy of the car park is not well-balanced as IPGS model. This shows no significant difference with respect to previous simulation results, which depend on random arrival rate with no departure. Based on this, in the following sections of the study, the results of random arrival type with no departure rate are used to analysis the CS and IP differences in the utilisation of the car parks.

The average capacity utilisation of three car parks based on random arrival type with no departure rate simulation results is illustrated in Fig. 9. It is obvious that the average capacity utilisation in the CS fluctuating for three car parks, which are 100, 98, and 65 percent. The capacity of the first car park is completely occupied, and the second one is almost filled up while only 2 out of 3 of the third one is used. However, in IPGS the capacity utilisation for the three-car parks is approximately balanced with rates between 83 and 93 percent.

5.2. *Estimation of extra tailpipe emission and value of wasted time*

The importance of balanced capacity utilisation is rising from the fact that finding available parking places is much more possible as the car parks do not reach their capacity. However, unbalanced capacity utilisation brings about extra search time in filled-up car parks. In this study, search time in the car park (unbalanced) at full capacity is accepted as 320 s following the observation made by Balijepalli, Shepherd and Kant (2015) for a surface car park. This time is denoted as extra search time for all vehicles, which direct to the closest car park after it reaches capacity. The simulation program counts those vehicles, which reach the car park after it is filled up. The number of those vehicles is given in Table 11 as Δ and Ω. This situation occurs in CS because the vehicles head toward the closest car park even after it reaches capacity. Because of this, extra search time, excessive fuel consumption, and emission arises. This emission is denoted as extra tailpipe emission, and the calculated results are given in Table 11 in terms of CO_2, CO, HC, and

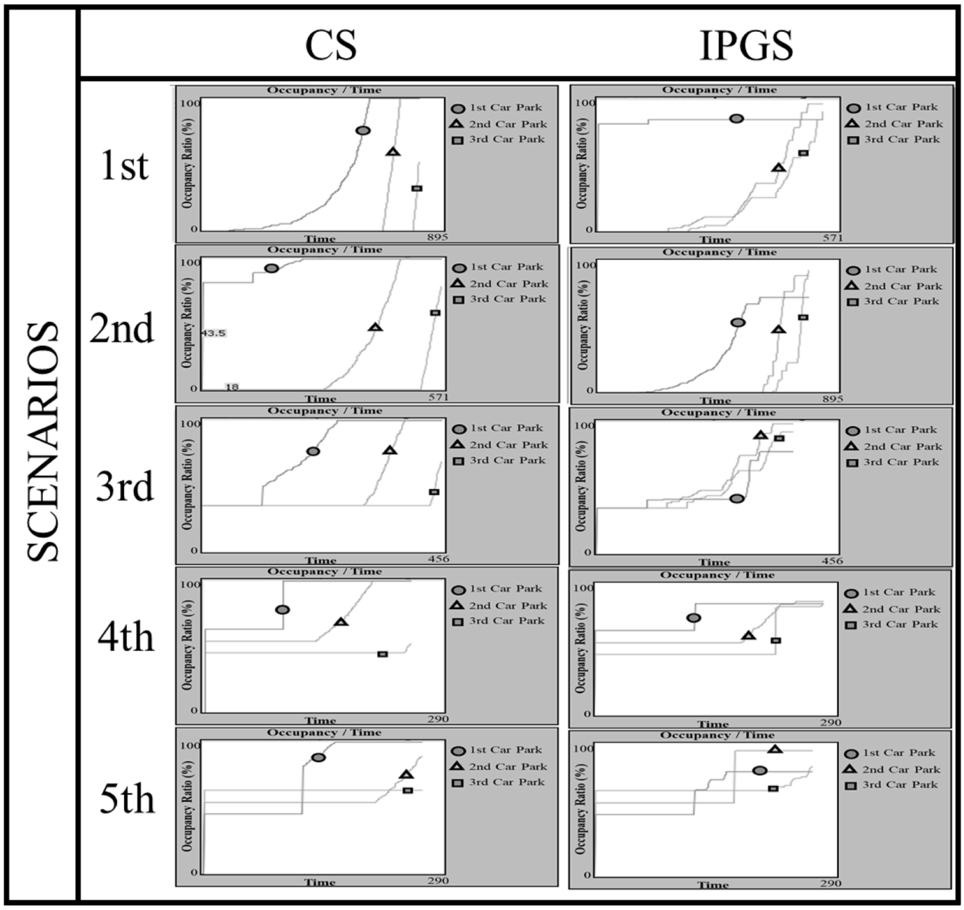

Fig. 8. Results of simulations with Poisson process arrival and departure rate.

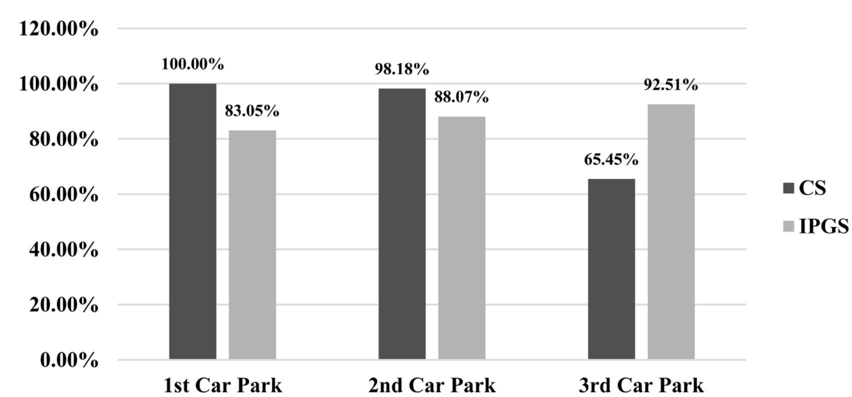

Fig. 9. Average Capacity Utilisation of Car Parks Based on Scenarios Results.

Table 11
Extra Searching Time and Tailpipe Emission in CS.

Scenario	Δ (unit)	Ω (unit)	Search time (s/veh)	CO_2 (g)	CO (g)	HC (g)	NO_X (g)
1st	425.00	150.00	320.00	229,260.32	11,440.08	1889.23	12,154.83
2nd	500.00	225.00	320.00	289,067.36	14,424.45	2382.07	15,325.66
3rd	275.00	100.00	320.00	149,517.60	7460.92	1232.11	7927.06
4th	150.00	25.00	320.00	69,774.88	3481.76	574.98	3699.30
5th	100.00	0.00	320.00	39,871.36	1989.58	328.56	2113.88

Δ : The number of vehicles arriving in the first car park after the park is filled.
Ω : The number of vehicles arriving in the second car park after the park is filled.

Table 12
Value of Wasted Time.

Scenario	Δ (veh)	Ω(veh)	Search time (h/veh)	Value of Time Turkish (Euro/h)	German (Euro/h)	U.K. (Euro/h)	French (Euro/h)	Total Deficiency Turkish (Euro)	German (Euro)	U.K. (Euro)	French (Euro)
1st	425.00	150.00	0.09	5.51	10.50	16.00	16.00	281	537	817.78	817.78
2nd	500.00	225.00	0.09					355	677	1031.11	1031.11
3rd	275.00	100.00	0.09					184	350	533.33	533.33
4th	150.00	25.00	0.09					86	163	248.89	248.89
5th	100.00	0.00	0.09					49	93	142.22	142.22

Δ : The number of vehicles arriving in the first parking lot after the lot is completely filled.
Ω : The number of vehicles arriving in the second parking lot after the lot is completely filled.

NO_x emissions.

Besides the pollutant gas emission, extra search time has a negative influence on transport economics when the VoT is considered. In Table 12, the total cost of wasted time is demonstrated for all simulation scenarios, considering VoT for Turkey, Germany, U.K., and French (Meunier, 2020).

Conclusion

In this study, which aims to determines the benefits of IPGS on capacity utilisation, five simulations for two models (M1 and M2) are executed in the multi-agent-based simulation program to make comparisons between IPGS and CS. The results of the simulations are compared in terms of capacity utilisation of car parks and the extra search time is evaluated, referring to pollutant gasses emission and VoT.

The comparison of the results demonstrates that in the CS model (M1), drivers tend to use the first car park, which is the closest to the startup point, and then the second car park respectively. Moreover, the third car park is preferred after the first and second car parks are filled up entirely, and its capacity utilisation is average at 65.45%. Because of the tendency to head toward the closest car park, drivers ingress into fully occupied car parks that result in the extra search time. This leads to a waste of time and excessive emission of harmful gases such as CO_2, CO, HC, and NO_x.

The simulation results of CS scenarios demonstrate that the amount of CO_2, CO, HC, and NO_x emissions due to the extra searching period are 398.71, 19.90, 3.29, and 21.14 g/s/veh respectively.

Additionally, the cost of the extra search period is estimated considering VoT for Turkey, Germany, U.K., and France. The results show that the costs of the extra search period per vehicle are 0.49 Euro for Turkey, 0.93 Euro for Germany, 1.42 Euro for U.K., and 1.42 Euro France.

Alternatively, the proposed IPGS model (M2) equilibrated the capacity utilisation of the three-car parks, and the capacity utilisation of car parks ranges between 83 and 93 percentages. So, the assistance of the IPGSs increases the probability of detecting an available parking place and avoid extra search time by balancing capacity utilisation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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