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Micro-Simulation of Car Drivers' Movements at Parking Lots

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Abstract

Drivers' movements across or within parking facilities contribute to various problems, *i.e.*, congestion, safety, and environmental effects. Micro-simulation can help to increase the understanding of drivers' movements and their effects on parking management. This study aims to develop a multi agent-based simulation tool to demonstrate its capability of studying driver movements across parking lots. The program was constructed using the multi-agent modeling environment NetLogo. The developed simulation tool allows to adjust features of the parking facilities. Additionally, vehicle travel time and parking occupancy indicators were integrated to investigate the efficiency of the parking.

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Keywords: NetLogo; drivers' movements; parking; simulation

1. Introduction

Parking facilities are important elements in the urban transportation system, especially in an era when the number of car owners is increasing. The increasing number of car users leads to an incremental demand of parking facilities. Congestion and environmental problems (*e.g.*, emission and noise) are also acknowledged as consequences of drivers search for parking [1]. According to Federal Highway Administration, parking-related accidents accounted for 49% of all mid-block crashes along major streets, 68% and 72% along collector streets and local streets respectively [2]. Additionally, when the demand of parking could not be satisfied, the parking shortages can create poor accessibility reputations of cities which might decrease the attractiveness to shoppers, tourists, and commuters.

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To satisfy the parking demand, constructing new parking facilities is one of the possible choices of many transportation experts and policy makers. However, construction of new facilities is not always possible due to lack of money, human, time, and land resources. Another solution that might be applied to meet the demand of parking is the optimization of parking facility usage. This approach seems to be more efficient since it consumes less resources. When optimizing parking facility usage, an appropriate and efficient layout of parking areas should be considered as one of the initial criteria. In order to have a proper design, understanding car drivers' movement across parking lots plays a decisive role [3]. Micro-simulation is widely considered as a method that studies the drivers' behaviors. For example, Bonsall and Palmer used PARKIT parking choice simulator to model car off-street parking behaviors of drivers [4]. Another application of micro-simulation is PARKAGENT. It is an agent-based model that was used to simulate the on-street parking behavior of drivers in Tel Aviv city [5]. However, these studies have focused on simulating the behaviors of the whole parking process or the choice of parking facility but not on the car drivers' movement across parking lots.

Among micro-simulation programs, multi agent-based modelling simulation environment of NetLogo has shown its advantages for behavioral simulation. This program allows researchers investigate the connection between micro-level behaviors of individuals, and macro-level patterns coming from their interactions. Also, NetLogo is an open-source software and quite simple but powerful and users can create their own models. Those advantages make it become a promising method for transportation researchers. Though NetLogo is quite popular in other fields, it has not been applied often in the transportation field yet [6]. Based on the current parking problem and the advantages of Netlogo, there is still need for further studies on application of NetLogo in drivers' movement simulation at parking lots. This study, therefore, aims to develop a micro-simulation of drivers' movements at the parking lot using the NetLogo environment. The developed tool will be validated with a case study using existing data [7].

2. Theoretical background

2.1. Factor influenced the parking movement at the parking lot

Parking movement at the parking lot includes two steps *i.e.*, route choice for parking strip, and route choice for parking space. These two steps are complex since they are influenced by many factors. The route choice for parking strip will be influenced by four factors. Firstly, the distance between the parking strip and the final destination affects the parking movement [4,8,9]. Secondly, the parking's attractiveness is another factor and this includes three sub-factors *i.e.*, driver's perception, the parking strip characteristics and parking strip's disutility [8,10]. Thirdly, guidance information signs and the queuing time at parking space also influence on this process [4]. Finally, the travel time of the route and the walking time from the parking strip to the desired destination also have effects on this decision [4,9].

Similar to the route choice for parking strip, the choice for parking space is also affected by many factors. The first one is the distance between the location of the parking space and the final destination. Again, the driver tends to choose the parking space which is closest to the final destination [9]. Distance between the parking space and the ticket machine also influences the choice of parking space [7]. Together with distance, the driver's gender is the second influenced factor *i.e.*, male prefers to park closer to the entrance of the parking lot. The car's size is the third one *i.e.*, bigger cars require to park at wider space while smaller cars lead drivers to choose a space which is occupied on both sides.

2.2. Parking indicators

Parking occupancy and average parking occupancy can be utilized to measure the effectiveness of the parking usage [11]. The parking occupancy indicator is a proportion of spaces occupied in a defined time interval. Based on the parking occupancy and number of observed time intervals, the average parking occupancy can be calculated. In simulation, the number of time interval influences both accuracy and duration of a micro-simulation run. The shorter time interval micro-simulation uses, the greater precision of the model results are. However, shorter time interval requires more computation [12]. Besides, the vehicle travel time, including travel time from the driver's vehicle current location at the car park and the searching time for the parking space at the parking strip will attract drivers choose the parking space and the parking lot [8]. Hence, this travel time can be used to measure the effectiveness of the parking lot.

2.3. NetLogo

NetLogo is a Multi-Agent-based Model which uses its own programming language to create models. Hence, it is not expandable and is only suitable for small systems [13]. However, NetLogo has many advantages. Firstly, NetLogo is a free and open-source multi-agent programming language and modeling environment for simulating natural and social phenomena [6,14]. Secondly, NetLogo can be easily learned and used. NetLogo language is simple enough for children to program but also advanced enough to serve as a powerful tool for users at the undergraduate level or higher with sophisticated systems [6,15]. NetLogo has extensive documentation and tutorials. Hence, it is particularly well suited for modeling complex systems developing over time. Modelers can give instructions to a big quantity of "agents" all operating concurrently, in order to explore connections between micro-level behaviors of individuals and macro-level patterns that emerge from their interactions [15]. Thirdly, NetLogo provides users a faster and more flexible way to investigate their systems, compared to studying them in reality. In simulation environment, users can explore system behaviors under various conditions [15]. Fourthly, since NetLogo was designed for both education and research, users are not only able to use the pre-built models but also authorized to modify them in order to adapt to certain scenarios. In case the pre-built models cannot fulfil the needs, users can create their own models by using NetLogo features *i.e.*, simple scripting language and user-friendly graphical interface. NetLogo are, therefore, utilized in various domains *e.g.*, biology, medicine, economics, psychology, computer science, transportation.

3. Methodology

3.1. Parking rules and indicators

The observed data and the findings of van der Waerden *et al.*'s study [7] were used to develop the simulation. Particularly, the observed data was used to calculate the rate of cars entering the parking lot. Additionally, this data was used for the simulation's case study. The findings were employed to build the movement rules for the simulation. In other words, the three influencing factors on choosing the parking spaces were used to set up the movement rules for cars in the simulation, *i.e.*, ticket payment, gender, and car size. Ticket payment is the most important variable which has the first priority to decide parking space. Gender and car size have less priority respectively as shows in Fig. 1.

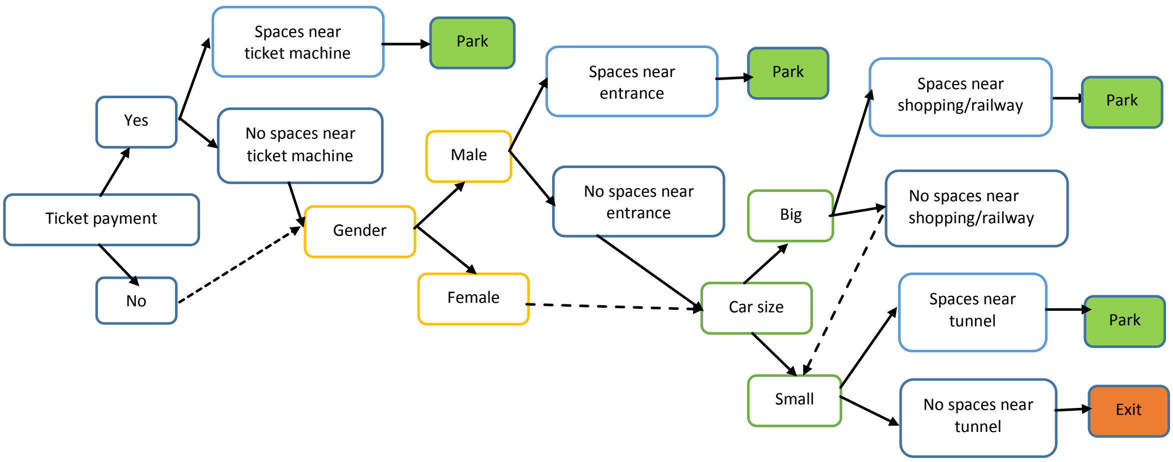

Fig. 1. Movement rules for the developed - simulation [7].

To evaluate the effectiveness of the parking facility usage, the vehicle travel time and average parking occupancy were measured [8,11]. The time interval used in measuring the average parking occupancy is one second. This short time interval avoids missing short-term parkers in the simulation [11].

3.2. Simulation design

The developed simulation includes three major steps, *i.e.*, global setting, car movement, and global updating.

Step 1 - Global setting

This step creates the global settings which include four sub-steps *i.e.*, creating parking layout, setting for simulation, setting for parking features, and setting for population.

Creating the parking layout: The random seed was initial set up in order to guarantee that the users can get the same results for every time running simulation. The parking layout included borders and characteristics and they were set up similar to the parking layout in Eindhoven [7]. The border of this parking lot was built by setting the coordinate limits for the patches. Next, six characteristics of the parking lot were created *i.e.*, entrance, exit, ticket machine locations, parking gate, different parking strips and parking spaces. Again, these characteristics were set up based on setting patches. One entrance and exit, ticket machine, gate and five different parking strips were set up similar to the parking layout in Eindhoven [7]. The gate was set up to automatically close when no space is available. In order to indicate the movement route for the cars, five different strips were created based on the movement routes (Fig.1). Additionally, all available parking spaces were set up the same color and they turned to another color to when the spaces were occupied. These colors informed the car the parking spaces' availability.

Setting for simulation: The time that users want to observe the simulation and initial car parked before running simulation were set up. Observed time was measured by ticks in simulation, corresponding to seconds in reality. Initial car parked was created before running simulation. A number of cars were randomly set up to park in the parking lot. And these initial cars were assigned the parking duration which is obeyed the parking duration of the parking lot

Setting for parking features: Three features of the parking were set up. The speed limit of the parking lot was set up for cars to follow. Cars can either run slower or faster (maximum 1 km/h) the speed limit. Car speed is decelerated when entering the parking space to reflect the actual parking time. This deceleration increases the time to get lot of the other cars. The "tick" time unit used in the developed-simulation tool is assumed as second in reality. Based on this assumption, the real speed was converted into the speed of simulation within the simulation code. The car enter rate is the number of cars entered the parking lot. This rate is randomly generated under assumption of Poisson distribution with defined rate [16]. Parking duration is the limit parking time for all cars. All car entered the parking lot were randomly assigned parking duration under assumption of Normal distribution with a defined rate [17].

Setting population: The percentages of the gender, car size *i.e.*, big, small, and the need ticket were assigned before running the simulation.

Step 2 - Car's movement

In this step, the characteristics of the cars, the entering cars, and the exiting cars were created.

Creating car with its characteristics: Six characteristics *i.e.*, genders, need ticket, car size, parking duration and speed, and vehicle travel time were assigned to cars. These characteristics were assigned under the population distribution in global setting step. Two car size *i.e.*, big and small were set up. Based on these characteristics, the car has its own movement direction and desired parking space. Each car was randomly assigned the parking duration and speed limit. These limits followed the parking duration and speed limit in global setting. To measure the parking effectiveness, the vehicle travel time was created. This time was counted from the moment of car entered the parking lot until the car parked.

Car enter: When entering, cars proceeded three steps *i.e.*, choosing desired parking areas, moving and looking for available spaces, parking. The car starts to choose its desired paring areas *i.e.*, near the entrance, ticket machine, shopping area, railway, tunnel. Then, the car moves and finds the available space. The first two steps are affected by the car' characteristics (Fig. 1). Next, the car parks when the available parking space satisfies its characteristics. In case there are no spaces or the available spaces are not qualified, the car exits. The travel vehicle time will be counted when the car entered the parking lot and it will be stored when the car parks. Meanwhile, the parking duration will start to deduct when the car parks.

Cars exit: While parking, the parking duration of its cars will be checked. The parking duration expires, the car will exit. In order to exit, the car will back to prepare for exiting. Depending on which location the car parked, different backing directions will be set up for the car. The parking space status will be set to available while the car back from its parked space. After backing, the car will follow the exit movement rules to leave the parking lot.

Step 3 - Global update

The global update was active during the simulation running. Particularly, the time, available parking spaces, plots, time observed and exporting results were updated. The whole process was set up to update within a tick in the simulation, corresponding to second in the reality. Every tick, the number of car park and number of available parking spaces were checked. The checking of available parking spaces were utilized to calculate the parking occupancy. The observed time that was set up in the global setting step was checked. The simulation automatically stopped when observed time is enough. The results of the simulation were exported after the simulation stopped.

3.3. Case study

To demonstrate the capability of the developed-simulation tool and evaluate effects of the parking duration and the speed limit on the parking efficiency, the case study in Eindhoven City is replicated. Three settings for simulation are generated using the data from Eindhoven case study. All scenarios have the same proportion in gender, car size, and need ticket. The rate of car enter is calculated from van der Waerden *et al.*'s study [7] as 1.02 cars/minutes. The initial number of occupied spaces is set at 30 parking spaces. Scenarios are different in setting of maximum parking duration and the speed limit in parking lot (Table 1). All scenarios are simulated in a period equivalent to six hours of real-time observation.

Table 1. Four scenarios of the simulation [7].

Scenarios	**Maximum parking duration (minutes)**	**Speed limit (km/h)**	**% of male**	**% of big car**	**% need ticket**	**Average rate of car enter (cars/minute)**	**# car occupied**
1st	120	15	43	70	91	1.02	30
2nd	120	20	43	70	91	1.02	30
3rd	240	15	43	70	91	1.02	30
4th	240	20	43	70	91	1.02	30

4. Results

4.1. Simulation

Parking layout

The parking lot was created including 160 parking spaces with one entrance, one ticket machine. Four exit points for pedestrian are located near the entrance, shopping area, tunnel, railway station. Cars can only exit near the entrance point. Each space is equivalent to one patch in the simulation. The parking space has a square-shape with dimension 5.5 x 5.5 meters which was modified from the recommendation of Urban Plan Institute [18]. This dimension was designed as an input button in the simulation interface. Hence, the dimension is adjustable which means that users can adjust it by replace the desired dimension in the input button (Fig. 2). The green indicated for available spaces while the red illustrated for occupied spaces. Besides, the parking lot was regionalized into five areas which are near entrance (E), ticket machine (M), shopping center (S), tunnel (T) and railway (R) areas. This regionalization helps cars moving and chose parking spaces.

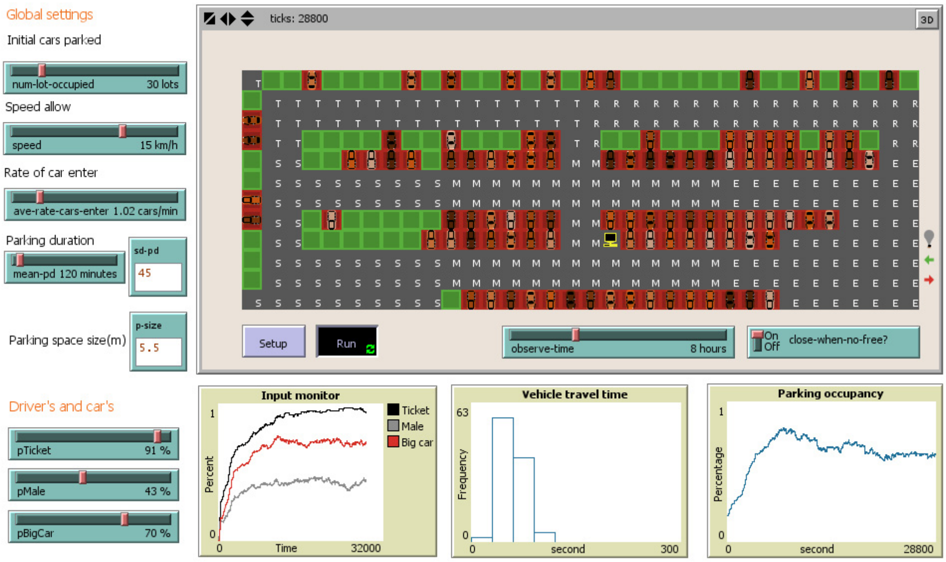

Fig. 2. Simulation interface of the parking simulation.

Parking settings

The number of occupied spaces were created in form of the sliders. This number was in a range from zero to 160 cars *i.e.*, the parking capacity (Fig. 2). The slides allow users to choose the desired setting for the simulation. The locations of occupied spaces can be different from each setup time due to the random process.

The gate was set up in form of the switch (on/off) in the developed-simulation. This helps the gate automatically closes when there are no available spaces and the bulb which is located near the entrance will turn on to inform the cars (Fig. 2). The average rate of entering cars was designed as a slider which can be adjusted from zero to six cars/minute. Besides, the observed time can be chosen as desire to stop running the simulation. Particularly, the observed time limit is 24 hours which is equivalent to the maximum parking duration of the parking layout.

Car settings

Each car will be assigned its characteristics, *i.e.*, payment ticket, gender, car size and speed, parking duration when entering the parking lot. These characteristics are displayed in form of adjustable sliders. Particularly, the users can move the sliders to choose the percentages of male, big car and need to pay the parking ticket entering the parking lot. Regarding to the speed, the car will be assigned the travel speed randomly within the limit set by the speed slider. The parking duration slider represents the mean of a normally distributed distribution in minute, with the corresponding standard deviation is designed as an input box. The parking space will be switched from red to green when the car exits. Three plots are draw during simulation, *i.e.*, input monitor plot, time to get lot histogram and parking occupancy curve (Fig. 2). The input monitor plot shows the number of three characteristics of cars entering the parking lot, *i.e.*, percentage of male, big cars and cars need to pay the parking ticket. The other plots monitor the two parking indicators of interests. Particularly, frequency of vehicle travel time indicates the number of cars spend 30, 60, 90, 120 seconds or more time to get to parking spaces. The parking occupancy depicts the occupancy percentage for each second.

4.2. Result of case study

The results of simulation was presented in Table 2. Majority of cars did not spend more than 60 seconds for parking. The number of cars parked within 30 seconds are larger than those of 60 seconds. At the same maximum parking duration, increasing speed will decrease the time to find and park car. However, the average parking occupancy decreased by 8.52%, *i.e.*¸ from 69.69% to 61.17%. When the maximum parking duration increased from 120 minutes to 240 minutes, more cars spent 60 seconds to get lot though this ratio was still smaller these numbers of 30 seconds. By contrast, the occupancy increased when the parking lot increased the maximum parking duration (Fig. 3). Particularly, the average percentage of occupied parking spaces increased by 12.76 when the speed limit is 15 km/h and this increment was 21.05% for the speed limit of 20 km/h.

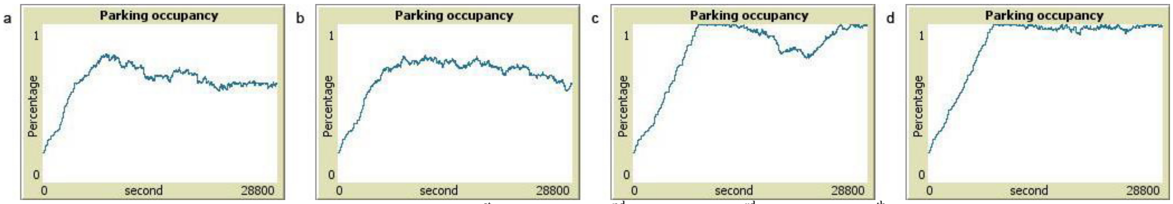

Fig. 3. Parking occupancy for (a) 1st scenario; (b) 2nd scenario; (c) 3rd scenario; (d) 4th scenario.

Table 2. Time to get lot and average occupancy of 4 scenarios.

Scenarios	**1st**	**2nd**	**3rd**	**4th**
Average parking occupancy	0.6969	0.6117	0.8245	0.8222
Vehicle travel time *(in second)*				
0	1	5	3	8
30	53 *(48.18)*	57 *(56.44)*	67 *(46.21)*	83 *(54.97)*
60	49 *(44.55)*	39 *(38.61)*	65 *(44.83)*	58 *(38.41)*
90	8 *(7.27)*	5 *(4.95)*	13 *(8.96)*	10 *(6.62)*
Total car parked/entered	110/111	101/106	145/148	151/159

** Number in the brackets are percentages*

5. Discussion

The main goal of this study was to attempt to develop a micro-simulation program for drivers' behaviors at the parking lot by using NetLogo. And the results have further strengthened that the developed-simulation tool can be applied to the drivers' behaviors at the parking lot. This study is consistent with the previous results which indicated the simulation ability of NetLogo in transportation [19,20]. Besides, the results of case study shows that the limited parking duration encourage short-term users. This result is incomplete agreement with the study of Litman [21]. The maximum parking duration and speed limit have reversed on both average parking occupancy of the parking lot and time to get lot of drivers at the parking lot. Besides, the differences of the results can be used to propose further studies about the influence of time on the efficiency of the parking usage.

This study presents a new approach for to simulate the drivers' behaviors at the parking lot. The policy makers, transport experts, parking managers can apply the developed-simulation tool to investigate the drivers' behaviors. When applying this developed-simulation tool, resources *i.e.,* time, money, human can be saved. Besides, the results of case study simulation show that the parking duration affects the parking occupancy. Hence, parking managers can reduce the parking duration to promote the short-term users. Speed limit adjustment could be considered as a countermeasure to decrease congestion problem in the parking lot. In case the policy makers or transport experts want to promote drivers to use bus or Park & Ride, adjustment of parking duration and speed limit can be considered to apply. Another potential application of this study is using the developed-simulation tool to find out the sufficient parking layout before building the new parking lot. This could be implemented by applying the developed-simulation tool to figure out the factors influence the drivers' movements at the parking lot. One possible implication is that the environmental effects of parking lot can be study. In other words, the amount of CO_2, evacuated into the environment from the movements of the car in parking lot, can be measured [22].

Due to the time constraint, this study only simulated the interactions between the drivers and the parking lot. In reality, when considering the parking lot, pedestrians are usually concerned [23]. Literatures shows that other factors *i.e.,* drivers' experiences, drivers' expectation, the travel time of the route, walking distance to destination also influenced on the drivers' behavior at the parking lot [4,9]. Though this current study has not integrated these factors yet, so far there are rarely studies simulated the drivers' experiences and expectation. Although the parking space size of this simulation cannot reflects the real size, it can be designed when the real space size is available. Besides, this study only developed the simulation for off-street parking instead of parking garages or on-street parking.

However, this study is the first step towards using NetLogo in parking. Hence, based on this study, the further studies for on-street parking, parking garages could be implemented.

6. Conclusion

The developed-simulation tool is promising platform to simulate the characteristics of the parking layout and the drivers' behaviors. In this study, we simulated the interaction between the drivers as well as between the drivers and the parking lot when the drivers are searching the parking spaces. Therefore, this can be applied to study the factors influence the parking behaviors of drivers, and the efficiency of parking usage in the parking lot. The results of four scenarios indicated that speed limit and maximum parking duration have effects on the efficiency of parking. Increasing speed limit helps drivers to save time to travel, to find parking space, and to park but decreases the average occupancy for the parking lot. By contrast, increasing parking duration limit helps increase the average occupancy for the parking lot while making drivers to spend more vehicle travel time. The simulation capability of this developed-simulation tool in drivers' behaviors is very exciting proposition. This can help us to save resources *i.e.*, time, money and human because of its open-source. Hence, further development of this developed-simulation tool with drivers' behaviors at the other parking facility types are needed to utilize the advantages of this simulation.

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