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2014•2015
SCHOOL FOR TRANSPORTATION SCIENCES
Master of Transportation Sciences

Master's thesis

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Supervisor :
Prof. dr. Gerhard WETS

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Thesis presented in fulfillment of the requirements for the degree of Master of Transportation Sciences

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ABSTRACT

Driver behavior is the major cause of many problems at the parking facilities, *i.e.*, congestion, unsafety, and negative environmental effects. Micro-simulation can help to understand drivers' movements and its effects to parking management. This study aims to develop a multi-agent-based simulation tool to demonstrate its capability on studying drivers' movements at a parking lot. The application was constructed using Netlogo and insights from literatures. Results from a case study using a specific parking lot in the city of Eindhoven, the Netherlands will be presented to validate the result of the simulation tool.

The developed-simulation tool allows to adjust the features of the parking facilities, *i.e.*, number of preoccupied parking spaces, maximum parking duration, rate of car entering the parking lot, and the speed limit inside the parking lot. Drivers' characteristics that influence the choice of parking space, *i.e.*, gender, car size, and ticket payment can also be adjusted. Vehicle travel time and parking occupancy indicators were integrated to measure the efficiency of the parking lot.

The results of this study contribute a profound development in using NetLogo to simulate car drivers' parking behavior. Simulation results from the case study suggest that the limits of speed and parking duration are the countermeasures to parking efficiency.

Highlights

- Developing a flexible multi-agent-based modeling tool for simulating drivers' movements at the parking lot.
- Parking lot features and car drivers' characteristics are adjustable towards users' expectation.
- Efficient parking indicators *i.e.*, the vehicle travel time and parking occupancy can be measured.
- Increasing the speed limit decreases the vehicle travel time but increases the parking occupancy.
- Increasing the maximum parking duration increases both the vehicle travel time and the parking occupancy.

Key words: The developed-simulation tool, car driver's movements, parking lot, NetLogo

1. INTRODUCTION

A parking facility is an important element in a transportation system, especially when the number of car owners is increasing. Because the increasing number of car owners leads to the incremental demand of parking facilities. Congestion, environmental problems *e.g.*, emission, noise, *etc.* are also surging as consequences of drivers' driving for parking (Arnott & Rowse, 1999). According to Federal Highway Administration, parking-related accidents accounted for 49% of all midblock crashes along major streets, 68% and 72% along collector streets, and local streets respectively (Humphreys, Box, Sullivan & Wheeler, 1978). Additionally, when the demand of parking could not be satisfied, the parking shortages can create poor accessibility reputations for cities which might decrease the attractiveness to shoppers, tourists, and commuters.

In order to satisfy the parking demand, constructing new parking facilities is one of the possible choices of many transportation experts, and policy makers. Nevertheless, it is not always sufficient, especially in the cases of scared money, human, time, and land resources. Another solution that may be applied to meet the demand of parking, is optimization of parking facility usage. This approach seems to be more sufficient, and efficient since it consumes less money, human, and time resources, as well as land area saving. When optimizing the use of a parking facility, a suitable and an efficient layout for a parking area should be considered as one of the initial criteria because of many reasons. Firstly, the appropriate layout not only maximizes the number of parking spaces but also enables the efficient flow of vehicles in the parking lot (Young, 1986). Secondly, the sufficient layout might affect the parking lot decisions, means of transportation use, or even the destinations such as the shopping, or leisure centers. Thirdly, the good parking layout can meet the demand of increasing parking. Fourthly, the sufficient layout may increase the attraction for cities which may lead to have more business coming to cities and workplaces. Fifthly, it also helps to reduce the congestion, emission, noises, and time lost. Finally, the insufficient layout causes traffic accidents for motorists or damages of vehicles (Stover & Koepke, 2002). Hence, the sufficient parking layout is responsible for satisfaction of the parking demand.

Getting a sufficient and an appropriate design or layout for a parking lot is not an easy task. Designers are required to apprehend the drivers' behaviors or movements at the parking lot since drivers' behaviors play a key role in travel demand management strategies (Van der Waerden, Timmermans & Rodrigue da Silva 2014). 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 parking behaviors of drivers (Bonsall & Palmer, 2004). Another application of micro-simulation is PARKAGENT. It is an agent-based model that was used to simulate the drivers' parking behaviors in Tel Aviv city (Benenson, Martens, & Birfir, 2008).

Among various micro-simulation programs, the multi-agent-based modeling simulation NetLogo has shown its advantages for behavior simulation. This program allows researchers to investigate the connection between micro-level behaviors of individuals and macro-level patterns coming from their interactions. Although NetLogo is quite popular in other fields, it has not been popularly utilized in transportation field yet (Sklar, 2007). Because of its advantages (*e.g.*, it is an open-source software, and quite simple but powerful, and users can create their own models) it has become a promising method for transportation researchers. As to the transportation area, there are some researches which applied NetLogo to develop micro-simulation models. Wilensky (1998) applied NetLogo to simulate the traffic at an intersection. Another application of NetLogo is to develop a model to control the traffic lights in a real-time traffic simulation (Wilensky & Stroup, 1999). Hjorth (2010) implemented NetLogo to test the congestion charging as a policy.

However, most of the studies focus on simulating the behaviors of the whole parking process, or the choice of parking facility but not the movement at the parking lot. Based on the current parking problems, and the advantages of Netlogo, there is still need for further studies on application of NetLogo in drivers' movement simulation at the parking lot. Therefore, this study aims to develop a micro-simulation program for car drivers' movements at the parking lot using NetLogo platform. The developed-tool will be validated with a case study using Van der Waerden Borgers & Timmermans' data (2003).

2. OBJECTIVES AND RESEARCH QUESTIONS

The study is designed to develop a multi-agent-based simulation tool for car drivers' movements at the parking lot by using NetLogo platform. The case study from the city of Eindhoven was replicated to illustrate the simulation capability of the developed-simulation tool. Some potential applications were proposed based on the findings of this study.

In order to reach these objectives, two questions were answered during this study. Firstly, whether the developed-simulation tool can replicate car drivers' movement at the parking lot or not? Secondly, whether the developed-simulation tool can measure parking effectiveness or not?

3. LITERATURE REVIEW

3.1 Factors influencing car drivers' movement

Various aspects of parking behaviors have been considered in literatures. These behaviors are different from the beginning to the end of the parking process. The driver usually goes through four steps *i.e.,* choice of parking, searching for a parking facility, parking movement, and duration of parking. (1) The first step of this process is a choice of parking. Particularly, the driver chooses between off-street or on-street facilities for parking, as well as chooses between free or paid parking places. If the driver decides to park at the off-street parking facility, he/she needs to choose a parking lot or a garage. (2) After deciding the parking facility, the driver continues to search for a parking location matched the chosen facility. (3) The next step of this parking process is the movement at the chosen parking lot/garage. This step includes two sub activities, namely route choice for parking strip, and space. Specifically, the driver makes a route decision which leads to a chosen parking strip. When the driver is at the parking strip, he/she chooses a space in which his/her car will be parked. (4) Finally, the driver decides parking duration. The decision of each step of this process will be affected by many factors. The two first steps of this process are meso-scales while the others are micro-scales. The driver's behavior varies on each step. Correspondingly, the influenced factors of these steps are also different. However, this research only focuses on the driver' movements at the parking lot or the micro-scale. Hence, only information related to parking movements is considered. In other words, the route choice for parking strip, and choice for parking space are deliberated.

Route choice for parking strip

Route choice for the parking strip indicates the decision of route leading the driver to the desired parking strip. This process is not simple and it has the same procedure as the parking search model of Thompson & Richardson (1998). However, instead of evaluating the parking facility, the driver will evaluate the parking strip to choose for parking. The process of route choice is created based on the modification of the parking search. This process includes a number of steps, and is initiated when the first search begins. First, the driver starts to search desired parking strip. Then, the driver evaluates the parking strip to have the information for the next step. In order to evaluate the parking strip, the driver assess attractiveness of the parking strip by comparing between satisfying levels associated to the current parking lot with his/ her expectations associated to other known parking strips. After evaluating, the driver makes a decision to accept this parking strip or not.

- If the driver feels satisfied to the parking strip, she/he accepts this parking strip. When this parking strip is accepted and parking spaces are still available, the driver parks her/his car. However, the driver may not accept to park at available spaces when he/she does not feel satisfied (the factors influence the decision of parking space will be discussed later). In this situation, the driver moves to find another free space or moves to another parking strip. In case of no available parking spaces at this parking strip, the driver can decide to wait for a free space. Besides, the driver can make an adaptive choice by leaving this parking strip. If the driver decides to wait for a free space at this current parking strip, she/he starts to re-evaluate this parking strip again to make a decision of accepting this parking strip or not. The same activities will be replicated for the next following steps.
- If the driver does not accept this parking strip, she/he determines a new route and drives to the next parking strip. Then, the evaluating process of the new parking strip will be started as the same procedure to the previous parking strip.

This process is complex because each activity of the whole process is influenced by many factors. Firstly, the searching activity may be affected by the distance between the parking strip and the final destination. In other words, the driver prefers to park as close as possible to the final destinations, or to minimize the total travel costs. Secondly, the attractiveness affects the evaluation of parking strip activity. Its attractiveness is affected by three factors *i.e.*, driver's perception, the parking strip characteristics, and parking strip's disutility (Thompson & Richardson, 1998). [1] The driver's perception includes initial perception made from the previous strips. In addition, the driver's perception is made during this current strip based on the departure of vehicles at this parking place. [2] The parking strip's characteristics contain the capacity, fee rate, and parking duration limit. [3] The final factor is parking strip's disutility which includes three cost dimensions, namely access, native, and waiting costs.

- Access cost occurs when the driver travels to a parking strip. The access cost includes the in-vehicle travel time from the driver's vehicle current location at the car park. Besides, this cost also considers the searching time for the parking space at the parking strip. The searching parking time is the travel time of a vehicle to find a space at the parking strip.
- Native (usage) is associated with a parking facility, including the monetary cost of the direct fee and expected fine as well as the egress time (*i.e.*, walking travel time from the car park to the final destination). Particularly, the egress or walking time is the time taken to travel from a parking strip to the final destination. And the fee paid for parking is estimated by multiplying the fee rate by the intended parking duration, if payment is required. If the fee is legally payable, but it is not mandatory (*e.g.*, on-street parking meters), the decision of whether or not to pay the fee involves consideration of the expected fine. The expected fine is estimated by considering the type of infringement (non-payment, exceeding the specified duration time limit) and the level of enforcement.

- Waiting cost only occurs when the driver waits in queue at a parking facility before entering this car park. And this cost is dependent on the vehicle's current location with respect to the parking strip being considered.

Thirdly, many researches have shown that the route choice process is affected by many factors. The information provided by Parking Guidance Information signs and the queuing time at parking space will influence on this process (Bonsall & Palmer, 2004). Additionally, the travel time of the route and the walking time from the parking strip to the desired destination have effects on this decision (Bonsall & Palmer, 2004; Young &Thompson, 1987; Young, 1986). Similar to the route choice for parking facilities, the route choice for parking strip may be addressed in conjunction with the route choice for parking space. Particularly, the number available parking strips and the number of drivers searching for parking strips will influence the parking search of the driver (Benenson et al., 2008). Hence, the parking strip search will be influenced by the number of available parking spaces of the strip and the number of the drivers searching for this parking strip.

Choice for parking space

The driver makes a decision of parking space when he/she is at a parking strip. Similar to route choice of the parking strip, there are many factors which impact on the choice for the parking space. The first factor 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 (Young, 1986). Furthermore, the distance between the parking space and the ticket machine also influences the choice of parking space (Van der Waerden, Borgers, & Timmermans, 2003). Together with distance, drivers' characteristic is the second influenced factor, *i.e.*, the age, the gender, ticket payment, car size, and number of people in the car. To be more specific, the older driver tends to avoid the parking spaces that are occupied on the right hand side. Meanwhile, the younger driver tends to avoid the parking spaces that are occupied on the left hand side. Regards to the gender, male prefers to park closer to the entrance of the parking lot. However, there is no evidence which shows female choose further parking space from the entrance. In case the driver needs to pay the ticket, the space near the ticket machine is preferred. The bigger car requires the driver to choose a wider space. By contrast, the smaller car leads the driver to choose a space which is occupied on both sides. As to the number of the people in the car, the more people in the car, the longer distance from the ticket machine the driver would like to park. Another factor is the time of the day. In the morning, the driver prefers to choose the parking space which is not occupied on both sides. In the meanwhile, the driver will choose the parking space which is occupied both sides in the afternoon. Besides, in the morning, the driver has a tendency to park near the ticket machine, the parking lot entrance, and the exit. In the afternoon, the driver may park further away from this reference point.

3.2 Parking indicators

In order to measure the effectiveness of the parking usage, parking occupancy, average parking occupancy can be utilized (Mathew, 2014). 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.

Parking occupancy = (Parking accumulation in a given period/parking capacity) x 100 where parking accumulation is defined as the number of cars parked in a defined time interval. This indicator is depicted in terms of accumulation curve which is obtained by plotting the number of spaces occupied regarding the given time.

Shorter time interval is more accurate because there are less chances of missing short-term parker. However, the shorter time interval consumes more resources *e.g.*, labor intensive, and costly (Mathew, 2014). 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 (Dowling, Holland & Huang, 2002).

Besides, the in-vehicle travel time and the searching parking times will attract drivers choose the parking space and the parking lot (Thompson & Richardson, 1998). In case of movements at the parking lot, these two types of time can be integrated into the vehicle travel time. The vehicle travel time can be used to measure the effectiveness of the parking lot. This is started to calculate when the car enters the parking lot, and is stopped when the car parks.

3.3 Agent-based modeling and simulation

An agent-based modeling and simulation (ABMS) is a bottom-up modeling approach that describes or defines potential interactions between the individuals of the system, *i.e.*, agents. It can capture emergent phenomena and simulate a diverse range of complex systems. ABMS' results are the micro-level behaviors which are resulted from the interactions between the agents. Hence, ABMS is appropriate to study the behavior of complex systems such as the transport system (Bonabeau, 2002).

One of the application of ABMS in transportation is activity-based models for the travel demand. Currently, ABMS has been attracted attention increasingly because it is more focusing on behaviors, compared to the trip-based four step models. Besides, ABMS has potential to achieve the reliability, and reactivity which is essential to address emerging transport concerns (Guo, Huang & Sadek, 2013). To be more specific, since the 1980s, traffic engineering experts have developed and applied ABMS as a current micro-simulation for the demand side of transport. In a micro-simulation, the agents (*i.e.*, the driver, vehicle) decide the speeds, accelerations/decelerations, lanes in which the vehicle run based on its own states (*i.e.*, position, current speed) and its perceptions of the environment (*i.e.*, headway to other cars). PARAMICS (Quadstone, 2004), VISSIM (Planung Transport Verkehr-AG, 2004), AIMSUM (Barcelo & Ferrer,1998), TRANSIMS (Guo, Huang & Sadek, 2013) are currently the well-known agent-based micro-simulation models.

Application of ABMS in transportation is currently increasing but there is not many researches focusing on parking. One of fundamental researches is PARKAGENT model (Benenson, Martens & Birfir, 2008). This agent-based model simulates the drivers' behaviors in a spatially explicit environment. The whole parking process *i.e.*, from searching for parking place to exiting the parking place was simulated. The simulation environment is built with the high resolution of the urban GIS data *i.e.*, traffic infrastructures (buildings, on-street/off-street parking facilities). This model illustrated a real case study from Tel Aviv city. The output of this simulation helps to show its advantages. One of its advantages is capturing the effects of non-heterogeneity of the driver population. Particularly, this model can simulate the complex different scenarios of the parking system in detail. The results of these different scenarios are the performance about the key values *e.g.,* searching time, walking distance, parking costs over different groups of drivers. Another advantage of PARKAGENT is that the number of drivers simulated is not limited. Besides, researchers can apply PARKAGENT to study the effects of additional parking supply at residential areas in which the parking places are inadequate. Hence, this model is more advanced than the traditional approach because it can simulate the parking place which is saturated. However, this model has some limitations. Particularly, PARKAGENT is only considered as the first step of simulation for the management of the saturated parking's situation. The potential policy intervention for the parking management is still not clarified. Another limitation is that PARKAGENT does not cooperate the other transport modes in its simulation.

Another application of ABMS is a simulation of truck parking in Toronto (Nourinejad, Wenneman, Habib & Roorda, 2014). The purpose of this model is evaluating impacts of dedicating on-street parking in Central Business districts. By cooperating the parking choice model, this model simulates decision of parking facilities/location of the driver. Compared to the traditional approach, this model replicates the important parking activities that are usually neglected in literatures, and not quantified in practical decisions *e.g.,* walking distance, congestion impacts, parking search time. Though this model is promising, there still exists some restraints. The validation of this model is still limited. In other words, the outcomes and the observed values are not similar. Hence, this model is needed to improve the accuracy. Furthermore, all trucks were assumed to make the same parking decision but they are different in reality. Particularly, various types of trucks *e.g.,* couriers, food delivery have different constrains on parking behaviors.

Guo Huang & Sadek (2013) developed a novel agent-based model to simulate the parking behavior at a university's parking campus. This novel model is integrated between the disaggregate activity-based-travel demand model (TRANSIMS) and MOVE2010 emission model. The TRANSIMS model provides the traffic routing and micro-simulation functions which focus on vehicle-related travel and associated parking search process. Meanwhile, MOVE2010 emission model focuses on the environmental aspect. Additionally, in order to simulate the optimistic and pessimistic behaviors of parking, the sequential game theoretic neo-additive capacity model was utilized. This theory helps to simulate the desired lots of the driver accurately. This mode is accurate and sensitive enough to evaluate sustainable transport strategies and policies for parking management. Because of MOVE2010 integration, this novel model can quantify the environmental cost of the parking search process which is rarely simulated in literatures. Hence, this model is potential to assess the effectiveness of parking management strategies and policies. However, this model is only designed to replicate the parking behaviors at a given hourly traffic distribution *i.e.,* the time of arrival to University's campus. Furthermore, only cars were simulated in this model but not buses or other transport modes.

3.4 Multi-agent based modelling and simulation

Although ABMS has more advantages than the activity-based model, it does not incorporate the adaptability of users' behavior. In order to solve this constraint, a multi-agent-based system simulation (MAS) can be used. MAS is suitable to simulate the behaviors of many agents in the transport system (Nguyen, Bouju & Estraillier, 2012). MAS is defined as a number of agents which interact with another through communication. Both an ABMS and MAS need agents as a core concept of modeling. An agent is defined as a software system which can take autonomous decisions/ activities and interact with its environment to meet the design objectives (Wooldridge, 2002). The agent has two important rotations *i.e.,* self-interested and autonomous which supports the agent to make independent decisions of what to do to satisfy the design objectives. In order to operate ABMS or MAS, a necessary structure of a model includes two criteria. First, all agents are equipped with a set of goals. Each time, the agent chooses an action which is believed as the best one to reach the design objectives. Second, each agent has a united internal set of rules which guide to make decisions. The agent's action/behavior is, therefore, directly influenced by the other agents. In case one agent wants to change another's behavior, it can only do indirectly by affecting some actions. These actions alter the best way for the second agent to achieve its own goal.

Currently, MAS application is increasingly utilized. There are several MAS platforms, *e.g.*, Madkit, Jade, Repast, GAMA. Expressly, Madkit is a platform written in Java, and built upon the Agent/Group/Role organizational model. This platform can help to simulate the role in groups, and can create artificial societies (Gutknecht & Ferber, 2000). Nevertheless, it poorly supports geographic data. JADE platform simulates the communication between agents but it does not support geographic data integration (Bellifemine, Poggi & Rimassa, 2011). Repast is also open-source, and written in Java but this platform can support well developed spatial data libraries. However, advanced GIS operations have to be programmed which is far from reach of modelers (North, Collier & Vos, 2006). Compared to other platforms, GAMA is more advanced since it provides a complete modeling and simulating environment for building spatially *i.e.*, the geographic information is well integrated in this simulator. However, this simulation has been not adapted yet, and the parameters cannot be adjusted or changed during the simulation (Amouroux, Chu, Boucher & Drougoul, 2009).

3.5 NetLogo

Compared to other platforms, NetLogo uses its own programming language to create models. Hence, it is not expandable and only suitable for small systems (Wilensky, 2009). 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 (Sklar, 2007; Wilensky, 2014). 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 or higher levels with sophisticated systems (Sklar, 2007; Tisue & Wilensky, 2004). NetLogo has extensive documentations and tutorials. NetLogo 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 (Tisue & Wilensky, 2004). 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 (Tisue & Wilensky, 2004). 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 fulfill 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.

In order to develop a micro-simulation in NetLogo, modelers work in three main feature tabs *i.e.,* Interface, Info and Code.

- The Interface tab is designed to provide users an ability to create and edit graphical elements including button, slider, switch, chooser, monitor, plot, output, and text. In order to control the content of these elements, as well as behavior of agents, a program needs to be written in the Procedures tab. In NetLogo, agents are represented as “turtles” and placed in a two dimensional canvas called “world”.
- The Information tab is a plain text editor utilized for documentation purpose. This tab is useful for either the programmer or other people to review and understand the system.
- Code is the procedure tab. This is a development environment which allows users to program content of graphical interface elements and behavior of turtles in form of “primitives”. Similar to other programming languages, some of NetLogo primitives operate on data structures *i.e.,* Turtles, agent-set, list, and string. Other primitives enable standard programming structures (*e.g.,* looping, branching, logic) and standard mathematical functions (*e.g.,* comparisons, trigonometry, statistics). There also exist primitives used for customizing interface components.

4 METHODOLOGY

4.1 Parking settings and rules

The observed data and the findings of Van der Waerden, Borgers, & Timmermans’ study (2003) were used to develop the simulation. Particularly, the observed data is used to calculate the rate of cars entering the parking lot. Besides, this data was used for the simulation’s case study. Together with observed data, 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 of the car driver when looking for a parking space. Gender and car size have less priority respectively as shown in FIGURE 1.

In particular, the first priority rule is that if the driver needs to pay the parking ticket, he/she will park near the ticket machine. In case there is no parking space near the ticket machine available, the male rule is applied. When there is no space which satisfies the male rule, the car size rule is used. Likewise, if the driver does not need to pay the ticket, the car will follow the gender rule. The second rule is based on the gender, *i.e.,* if the driver is male, he will park near the entrance point. In case the driver is female or there is no place near the entrance point, the third rule is used. The third rule indicates that big car size will park near shopping center or the railway station exit points. In case the car size is small, the driver will park in other spaces *i.e.,* near tunnel area. The driver will exit if these three rules are not satisfied.

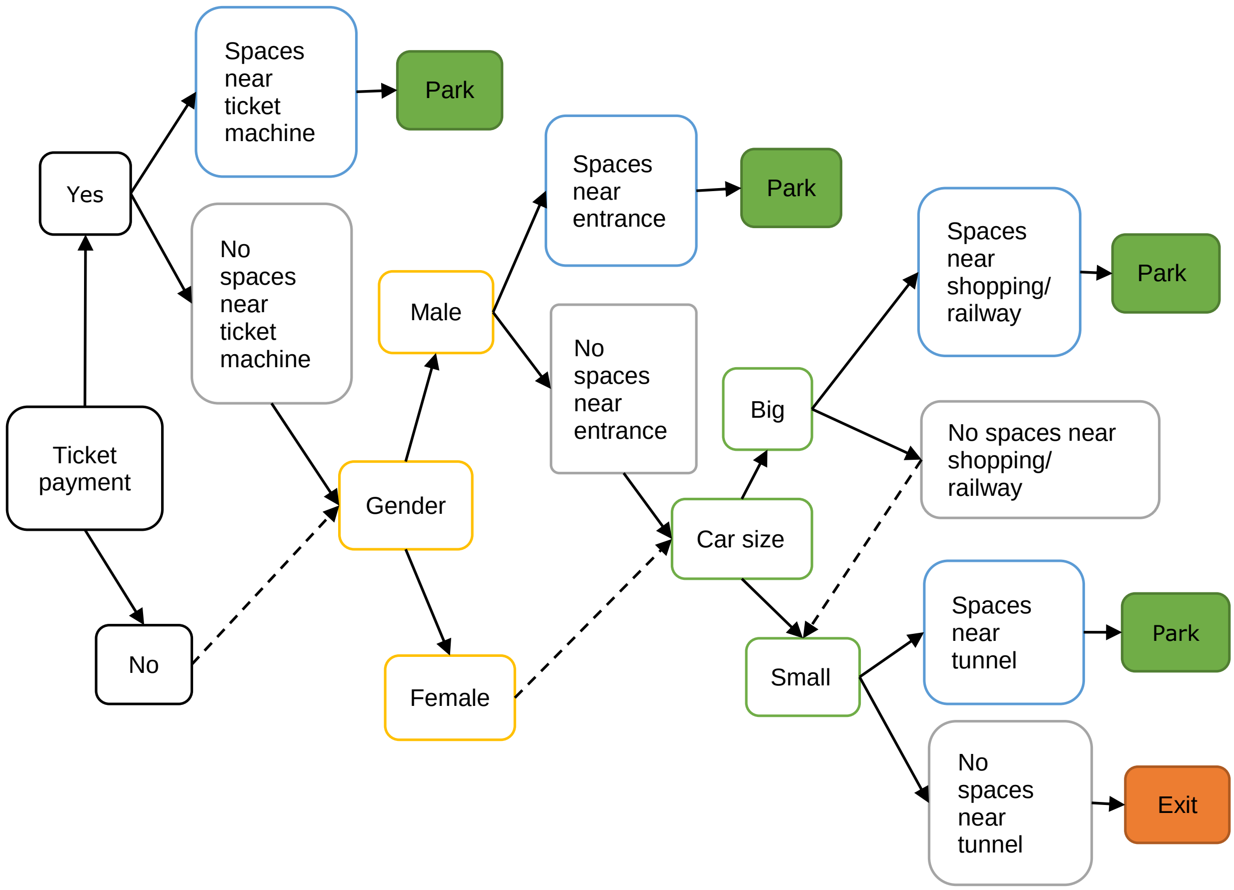

FIGURE 1 Movement rules for the simulation (based on Van der Waerden, Borgers & Timmermans, 2003).

4.2 Parking indicators

In order to evaluate the effectiveness of the parking facility usage, two indicators were measured *i.e.*, the vehicle travel time and the average parking occupancy (*e.g.*, Mathew, 2014; Thompson & Richardson, 1998). The time interval used in measuring the average parking occupancy is one second. This short time interval can avoid missing short-term parkers in the simulation (Mathew, 2014).

4.3 Simulation design

The process of developing the simulation using NetLogo platform includes three steps, *i.e.*, global setting, car movement and global updating (FIGURE 2). These steps are described detail in following subsections.

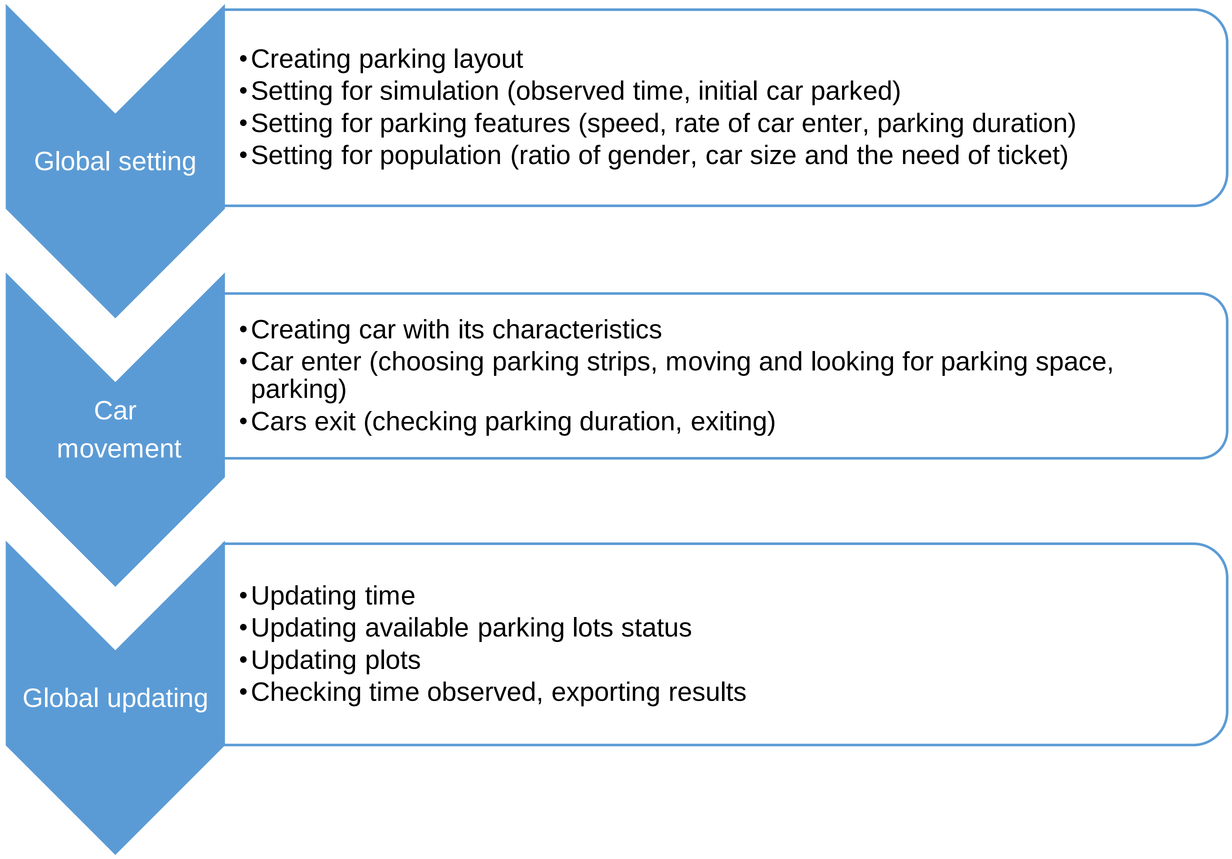

FIGURE 2 Three stages of simulation development procedure summary.

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, 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 of the parking lot. 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 (Van der Waerden, Borgers, & Timmermans, 2003). The gate was set up to automatically close when no space available. In order to indicate the movement route for the cars, five different strips were created based on the movement routes (FIGURE 1). Additionally, all the 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 observed time and initial car parked before running simulation were set up. The observed time was the time that users want to observe the simulation. It was measured by the "tick" time in this simulation. 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 *i.e.*, speed, rate of car enter, parking duration. The speed limit of the parking lot was set up and all cars enter followed this speed. Thus, some cars can either run slower or faster (maximum 1 km/h) the speed limit. The 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 rate of car enter is the number of cars entered the parking lot. This rate is randomly generated under assumption of Poisson distribution with defined rate (Haight, 1967). 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 (Walck & Group, 2007).
- Setting population: The distribution of the gender, car size *i.e.*, big, small, and ticket payment were assigned before running the simulation. Particularly, the percentages of male, big car entered the parking lot during the observed time. The percentages of drivers need tickets entered the parking lot.

Car's movement

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

- Creating car with its characteristics: All cars were assigned eight characteristics *i.e.*, shape, color, gender, ticket payment, car size, parking duration, parking speed, and vehicle travel time. All cars were created the same shapes but different colors. The gender, ticket payment, and car size characteristics of each car were assigned under the population distribution in global setting step. Two car size *i.e.*, big and small were set up for cars. Based on these characteristics, the car has its own movement direction and desired parking space (FIGURE 1). Each car was randomly assigned the parking duration and speed limit. The parking duration is assumed following the Normal distribution. In order 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 proceed three steps *i.e.*, choosing desired parking strips, moving and looking for available spaces, and parking. The car starts to choose its desired parking strips *i.e.*, near the entrance, ticket machine, shopping area, railway, and tunnel. After choosing the parking strips, the car moves and finds available spaces. The first two steps are affected by the car' characteristics. Expressly, its own characteristics *i.e.*, ticket payment, gender, car size decide its movement direction and its desired parking space (FIGURE 1). Next, the car parks when the available parking space which 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 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. When 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.

Global update

The global update was active during the simulation running. Particularly, the time, available parking spaces, plots, observed time, and exporting results were updated. The whole process was set up to update within a tick in this simulation, corresponding to second in the reality. Every tick, the number of car park and number of available parking spaces are 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 is also checked. The simulation automatically stopped when observed time is run out. The results of the simulation are exported after the simulation stops.

4.4 Case study simulation

In order to demonstrate the capability of the developed-simulation tool, and to evaluate effects of the parking duration restriction, and the speed limit on the parking efficiency, the case study in the city of Eindhoven is replicated. FIGURE 3 shows the parking lot layout used for the simulation. The parking lot has two lanes for drivers, corresponding to the superimpose arrows. Particularly, the blue arrows indicate the direction of cars entering the parking lot. Meanwhile, the yellow and white arrows depict the direction for exiting. When the car reaches the parking lot without parking, it will follow the exit movement routes. Three exit movement directions are applied for cars parked in different strips. Cars parked at yellow, white and red spaces will exit following the yellow white and red arrows, respectively.

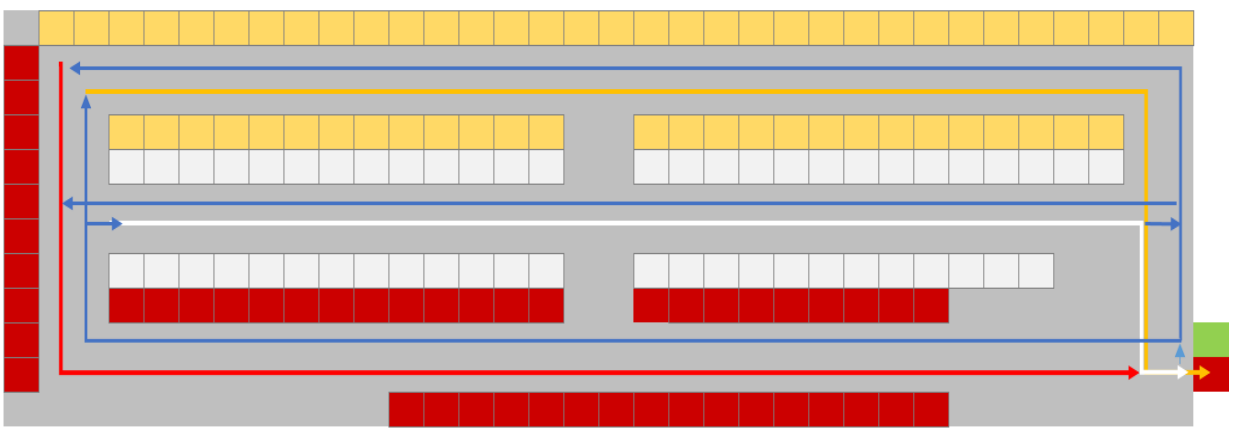

FIGURE 3 Car movement directions in simulation.

The exit routes are represented with red, white and yellow arrows, correspond to the three areas. The blue arrows are the enter routes.

Three settings for simulation are generated using the data from the Eindhoven case study. All scenarios have the same proportion of gender, car size, and ticket payment. The rate of cars entering is calculated from Van der Waerden, Borgers, & Timmermans' study (2003) 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 eight hours of real-time observation. This observed time is sufficient enough for all cars consume all the parking duration of 120 minutes and 240 minutes.

TABLE 1 Four scenarios of the simulation (Van der Waerden, Borgers & Timmermans, 2003)

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

5. RESULTS

5.1 The developed-simulation tool interface

Parking layout

The parking lot was created including 160 parking spaces with one entrance, one ticket machine (yellow computer icon, FIGURE 4). Four exit points for pedestrians 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 (1990). 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 replacing the desired dimension in the input button (FIGURE 4). All parking spaces are colored with green when they are available and they turn to red when they are occupied. In order to support for parking movement rule, the parking lot was regionalized into five strips which are near entrance (E), ticket machine (M), shopping center (S), tunnel (T) and railway (R) strips. This regionalization helps cars to identify these strips when cars move, and chose parking spaces.

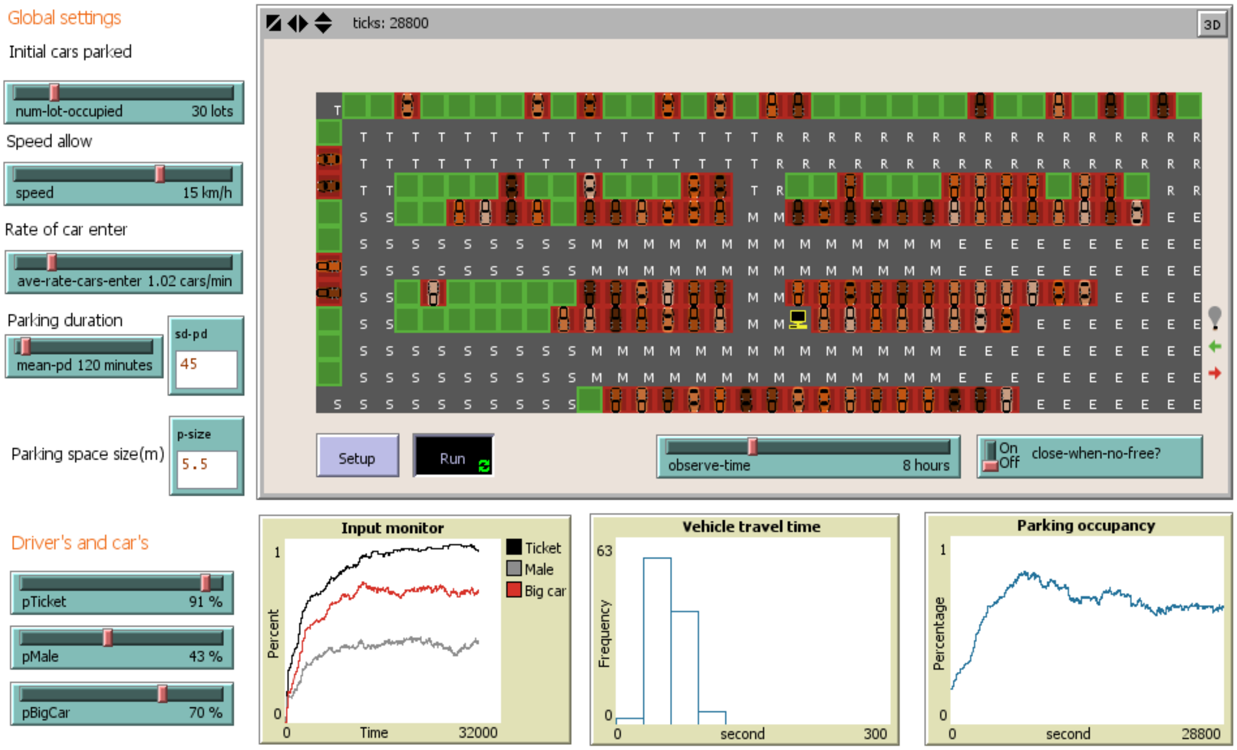

FIGURE 4 Parking lot simulation interface.

Parking settings

The number of preoccupied spaces were created in form of the slider. This number was in a range from zero to 160 cars *i.e.*, the parking capacity (FIGURE 4). The slider allows users to choose the desired setting for the simulation. The locations of preoccupied space are the same for each setup time due to the random seed.

The gate was set up in form of the switch (on/off) in the developed-simulation. If the button is switched on, the gate is automatically closed when there are no available spaces and the bulb which is located near the entrance will turn on to inform the cars (FIGURE 4). The rate of car entered 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.*, ticket payment, gender, car size, speed, and parking duration when entering the parking lot. These characteristics are displayed in form of adjustable sliders. The users can move the sliders to choose the percentages of male, big car, and ticket payment entering the parking lot.

Regarding to the speed, the cars 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.*, inputs monitor plot, vehicle travel time histogram and parking occupancy curve (FIGURE 4). The input monitor plot shows the number of three characteristics of cars entering the parking lot, *i.e.*, percentage of male, big car, and ticket payment. 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.

5.2 Case study in the city of Eindhoven

By utilizing the observed data and findings from Van der Waerden, Borgers & Timmermans' study (2003) *i.e.*, rate of car enter is 1.02 cars/ minutes, 30 spaces are initial occupied, 43% of drivers are male, 70% of cars are big size and 91% of cars need ticket, the results of simulation was presented in TABLE 2.

TABLE 2 Vehicle travel time and average parking occupancy of 4 scenarios

Scenarios		1st	2nd	3rd	4th
Average parking occupancy (%)		63.54	67.37	83.19	87.37
Vehicle travel time (in second)					
	0	2	10	3	7
	30	56 (57.14)	54 (60.04)	73 (45.91)	82 (53.59)
	60	38 (38.78)	33 (37.08)	72 (45.28)	63 (41.17)
	90	4 (4.08)	2 (2.88)	12 (7.55)	7 (4.57)
	120	0	0	2 (1.26)	1 (0.67)
Total car parked/entered		98/100	89/99	159/162	153/160

** Number in the brackets are percentages*

The results in TABLE 2 illustrate that the majority of cars did not spend more than 60 seconds in vehicle travel time for parking. The number of cars parked within 30 seconds are larger than those of 60 seconds, especially for 120-minute parking duration scenarios (1 and 2). However, the small ratios of car spent more than 90 seconds for parking when the parking duration is 240 minutes.

At the same maximum parking duration, increasing speed will decrease the travel vehicle time, as well as increase the average parking occupancy. The average parking occupancy increased by 3.83% *i.e.*, from 63.54% to 67.37% for the scenarios of 120-minute parking duration. Similarly, the average parking occupancy of 240-minute parking duration scenarios increased by 4.18% *i.e.*, from 83.19% to 87.37% (TABLE 2, FIGURE 5).

However, when the maximum parking duration increased from 120 minutes to 240 minutes, more cars spent 60 seconds to travel and park though these ratio were still smaller than these numbers of 30 seconds. Besides, there were some cars needed to spend 120 seconds in vehicle for parking. By contrast, the average parking occupancy increased by 19.65% from 63.54% to 83.19%

when the parking limit was 15km/h. This increment was 20% for the speed limit of 20km/h *i.e.*, from 67.37 to 87.37%. Interestingly, the parking lot were fully occupied for some observed second intervals when the parking duration were 240 minutes (FIGURE 5).

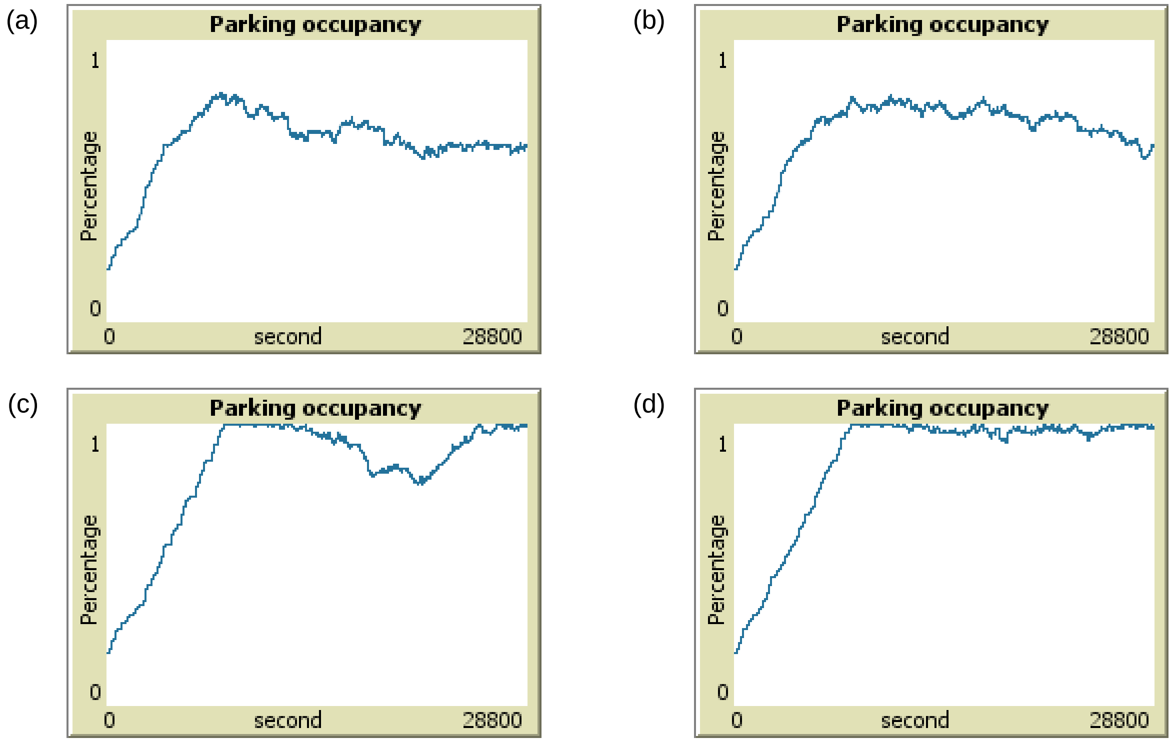

FIGURE 5 Parking occupancy for four scenarios.

(a): 1st scenario, (b): 2nd scenario, (c): 3rd scenario, (d): 4th scenario

6. DISCUSSION

The main goal of this study was to attempt to develop the micro-simulation program for drivers' behaviors at the parking lot by using NetLogo. 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 (Hjorth, 2010; Wilensky, 1998; Wilensky & Stroup, 1999). The users can adjust desired characteristics of the cars or the parking lot for their simulation. Also, the results confirm the study of Litman (2006). Limits of parking duration can encourage the short-term users because it decreases the parking occupancy. This study presents a new approach for to simulate the drivers' behaviors at the parking lot. The policy makers, transport experts, and 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 scenarios show that both the parking duration and speed limit constraints affect the parking efficiency. Because the parking duration affects the parking occupancy, parking managers can adjust the parking duration, and/or parking speed to promote the parking occupancy. The speed limit adjustment could be considered as a countermeasure to decrease congestion problem in the parking lot by reducing the vehicle travel time. In case the policy makers or transport experts want to promote drivers use bus, or Park & Ride, decrease of parking duration and speed limit can be applied. 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 can be implemented by applying the developed-simulation tool to figure out the factors influence the drivers' movements at the parking lot. Furthermore, the environmental effects of parking lot can be attractive attention of this simulation. In other words, the amount of CO_2 evacuate into the environment from the movements of the car in parking lot, can be measured by applying this simulation (Agency United States Environmental Protection, 1996).

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 (Ransford, 2009). Literatures show that other factors *i.e.,* drivers' experiences, drivers' expectation, parking guidance information, the travel time of the route, walking distance to destination, and time of day also influence on the drivers' behavior at the parking lot (Bonsall & Palmer, 2004; Young &Thompson, 1987; Young, 1986). 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 should be implemented.

7. CONCLUSIONS

The developed-simulation tool is promising platform to simulate the effects of changes in the characteristics of the parking layout and the drivers' behaviors. This developed-simulation tool's characteristics are modifiable under the users' expectation. In this study, we simulated the interaction between the drivers as well as between the drivers and the parking lot when the driver is 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 the case study indicated that speed limit and maximum parking duration have effects on the parking efficiency. Increasing speed limit helps not only drivers to save time to travel and find parking space but also increase the average parking occupancy for the parking lot. Similarly, increasing parking duration limit encourage the average occupancy for the parking lot but it makes 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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