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Mathematical Modeling of a Fuzzy Logic-Based Car Parking System

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ABSTRACT

This paper presents the mathematical modeling of a fuzzy logic-based car parking system. Many people are facing problems parking vehicles in parking lots in most urban cities. The technology of fuzzy-based systems is necessary for all vehicle users to acquire parking slots in cities. A smart parking system helps in obtaining information about available parking spaces, organizing and processing it, and then placing the car in a certain position. The method adopted makes use of a fuzzy-based smart car parking system to develop the usage of small parking spaces for parking lots to allow the parking of vehicles based on their weight. A set of rules was used in the fuzzy logic to control two sets of parking decisions, namely the vehicle entry decision and the in-park decision, by bearing in mind the weight of vehicles and the availability of parking spaces in the parking mall. The results obtained show that the smart car parking system keeps the availability of parking lots in equilibrium, depending on the entry and exit of vehicles. In conclusion, it was discovered that the total number of vehicles granted entry at each time interval depends on the availability of parking lots on each designated floor.

Keywords: Car parking system; fuzzy logic; mathematical modeling; parking lot; parking decision; Weight of the vehicle

1.0 INTRODUCTION

There are large numbers of people or organizations searching for parking spaces, thereby contributing to traffic congestion in large cities. Again, a lot of vehicles searching for parking spaces contribute to about 30% of traffic congestion experienced in large city areas (Sakthivel et al., 2020). On a daily basis, each vehicle on the road wastes 10–20 minutes cruising for a vacant parking spot. This situation leads to a great loss of time and money and also discourages drivers efforts to look for parking spaces (Bhonge and Patil, 2013). Presently, transportation fare has increasingly become an important economic, environmental, and political issue. As the urban population increases, there is an increase in the density of urban mobility, and this has brought about several transportation problems (Sathya and Kumaresan, 2017). The majority of the world's population lives in cities. With the exponential increase in car population and urbanization, issues of obtaining parking places for all vehicles, efficient management of available parking lots, and ensuring the security of the parking spaces have become increasingly difficult (Geng and Cassandras, 2013).

To tackle environmental challenges caused by traffic congestion as a result of searching for parking spaces in order to improve economic opportunities, numerous countries seek to improve and manage their existing transportation systems and road infrastructure to enhance traffic flow, mobility, and safety. One instance of such a response is the building and deployment of guidance-based systems, such as parking guidance and information (PGI) systems, for better parking management (Patil and Sakore, 2014). With the advent of the Internet of Things (IoT) and sensing technologies, smart parking has the potential to address these challenges. The Internet of Things has gone a long way toward utterly altering habitual human behavior by providing them with numerous facilities and comfort options to have ease in everyday life. Equipped with an Internet connection and sensor networks, electronic devices in the digital world are connected through IoT technology (Lee, 2019). A smart parking system (SPS) is a system that employs IoT devices or related sensors to acquire real-time data regarding park availability so as to reduce the time required in searching for parking slots (Reve and Choudhri, 2012). An automated parking system can be designed to provide more parking spaces for the same piece of land, and the driver drives up to a bay at the entrance of the parking lot, leaves the car, and machines move the vehicle automatically to its allocated spot (Canli and Toklu, 2021). A fuzzy rule is a form of algorithm that gives a qualitative relationship between two or more variables. This implies that the input variable and its variables influence the output variable. This rule through the relationship is an (if-then) form with vague information and a major mathematical principle that these rules are dependent on, and this gives the basics of the extension principle, which operates on fuzzy sets from inputs to outputs, and so the work of these rules is mainly through this principle (Hatte et al., 2020). In order to overcome the problems faced by people in some cities when parking vehicles in parking lots, the researchers carried out research on the modeling of a fuzzy logic-based car parking system to control the vehicle entry decision and the in-park decision in the parking mall. The statement of the problem is that many people are facing problems parking vehicles in most urban cities. The objective of the study is to develop a mathematical model of a fuzzy logic-based car parking system to alleviate the situation.

2.0 MATERIALS AND METHODS

The materials used in this paper consist of hardware and software materials: Arduino-UNO Controller, Arduino integrated development environment (IDE) software, and MATLAB/Simulink software. The smart car parking system utilizes the principle of mathematical modeling through the Mamdani fuzzy inference system (MFIS). In this type of parking system, decisions must be taken by any smart car parking system from the user to a parking lot on the cloud database using the internet of things. Smart car parking systems are designed to save stress and time in determining a safe parking lot for a parking system. The weight transducers are devices used to sense the weight of vehicles and convert it to an electronic form using Arduino. Again, Arduino sends this signal to the MATLAB/Simulink smart car parking system based on fuzzy rules, and the fuzzy logic-based smart car parking system served as a rule decision for the hardware component. Again, the weight transducer detects when a vehicle enters the park and when a vehicle leaves the park. Also, the transducer collects and sends records for the availability of a parking lot for a light, medium, or heavy-weighted vehicle once a parking lot is free. The block diagram of the smart car parking system is shown in Figure 1, and Table 1 shows the weight ranges for light, medium, and heavy-weighted vehicles for each user.

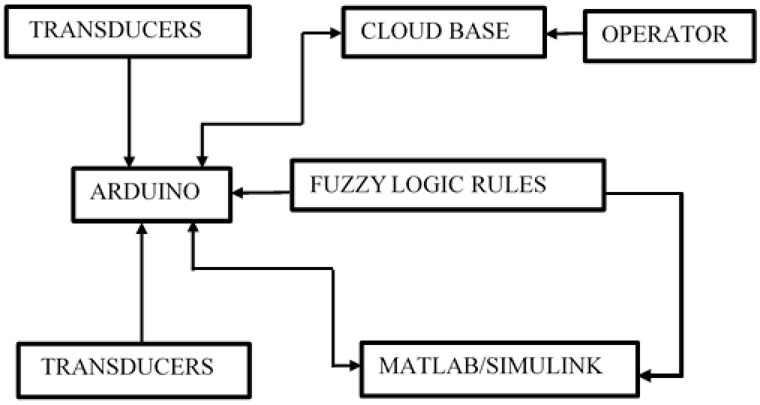

Figure 1: Block diagram of a smart car parking system

Table 1: Weight ranges for light, medium and heavy weighted vehicles for each user

Vehicle Type	Average weight of vehicles
Light weighted vehicles	2000 to 4000 pounds
Medium weighted vehicles	3500 to 6000 pounds
Heavy weighted vehicles	5000 to 8000 pounds

2.1 Mathematical description of the fuzzy logic system of the smart system

Let the behavior of the smart parking system during vehicle entry for n vehicles be denoted by $P_s = i = 1, 2, 3, \ldots n$, then let and t indicate the availability of the presence of a free slot and the availability of none, while c, d, j indicate the presence of a light, medium, and heavy weighted vehicle, and c_1, d_1, j_1 indicate the presence of a light, medium, and heavy parking lot in the garage in each of the P_{si} set. Also, let V_1, V_2 and V_3 be:

$V_1 = \{q,t\}$ (1)
$V_2 = \{c, d, j\}$ (2)
$V_3 = \{c_1, d_1, j_1\}$ (3)

This can be attached to each smart system P_{si} of a fuzzy subset, B_i of V_1, V_2, V_3 if;
$\{n_{iq}, n_{it}\}, \{n_{ic}, n_{id}, n_{ij}\}$ and $\{n_{ic1}, n_{id1}, n_{ij1}\}$ (4)

This equation (4) represents the number of entities showing success at each of the smart system P_{si}. The membership function for each is given as follows:

$$m_{fV1} = \begin{cases} 1 & if\ \frac{n}{2} < n_{ix} \leq n \\ 0 & if\ 0 \leq n_{ix} \leq \frac{n}{2} \end{cases} \tag{5}$$

Also,

$$m_{fV2} = \begin{cases} 1 & if\ \frac{2n}{3} < n_{ix} \leq n \\ 0.5 & if\ \frac{n}{3} < n_{ix} \leq \frac{2n}{3} \\ 0 & if\ 0 \leq n_{ix} \leq \frac{n}{3} \end{cases} \tag{6}$$

Again,

$$m_{fV3} = \begin{cases} 1 & if\ \frac{2n}{3} < n_{ix} \leq n \\ 0.5 & if\ \frac{n}{3} < n_{ix} \leq \frac{2n}{3} \\ 0 & if\ 0 \leq n_{ix} \leq \frac{n}{3} \end{cases} \tag{7}$$

Then, the fuzzy subset A_i of V_i corresponding to P_{si} has the following form:

$$f_{Vi} = \left\{\left(x, m_{fV_i}(x)\right) : x \in V\right\}, i = 1,2,3 \ldots..n \quad (8)$$

It is necessary to represent all possible overall state of the smart system entities during the corresponding process by considering the fuzzy relation W, in V^3 of the form:

$$W = \{(P_s, m_V(P_s)) : S = (x, y, z) \in V^3\} \quad (9)$$

2.1.1 Fuzzy inference system for the vehicle entry decision

The weight of the vehicle (WOV) and availability of parking space (AOP) are the variables considered for the vehicle entry decision. The weight of the vehicle is measured by the weight transducer, and the weight transducer carries out the motion weight of all vehicles approaching the parking mall and sends this data to the database for availability of parking lots. The availability of parking space for light, medium, and heavy-weighted vehicles was checked by the radio frequency identification (RFID) sensor that reports back to the database cloud.

The membership function of weight of vehicle (WOV) is arranged in line with the triangle functions, and the vehicle weight has three membership functions as shown in Figure 2.

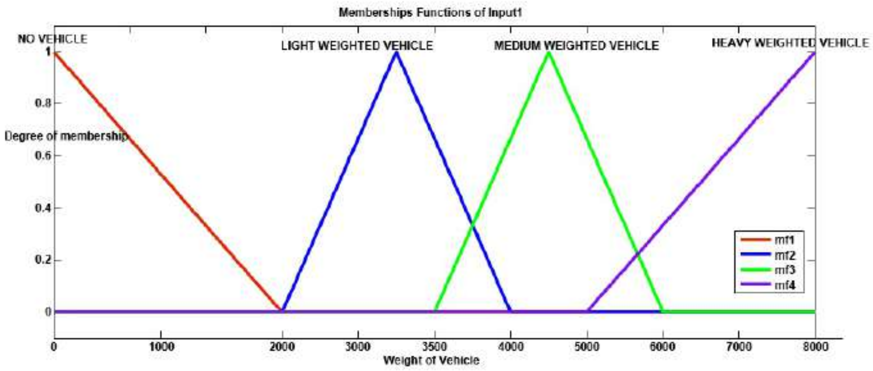

Figure 2: Input variable 1 for weight of vehicle with membership functions

The availability of parking space variable is composed of only two memberships, as shown in Figure 3, and the fuzzy criteria for the availability of packing spaces are shown in Equations (14) to (15).

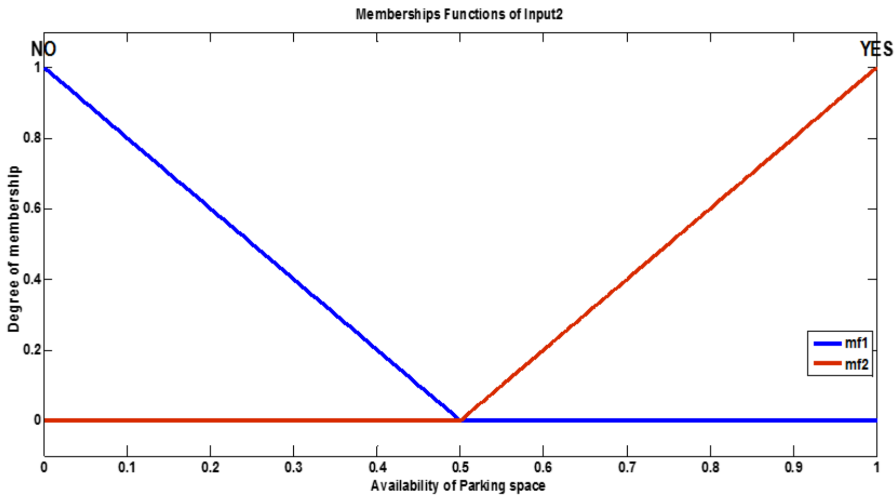

Figure 3: Input variable 2 for availability of parking space with membership function

The output variable is the result of the decision around the inputs and its membership functions, which include NO_ENTRY and YES_ENTRY with a range of 0 to 1.

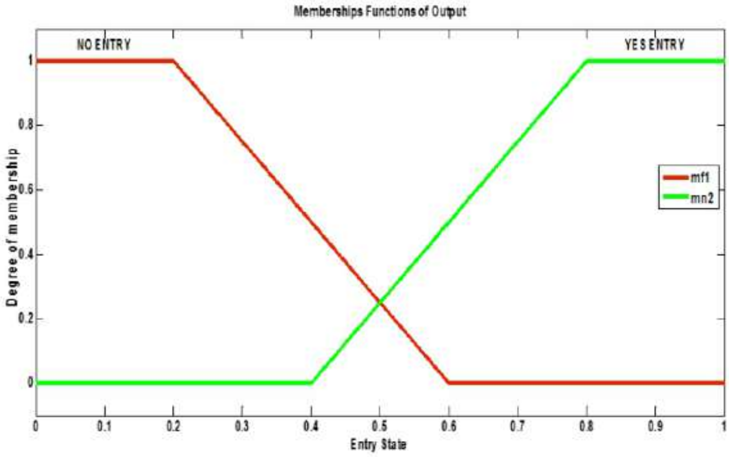

Figure 4: Output variable for entry decision with membership functions

$$m_{fno\_vehicle} = \begin{cases} \frac{2000-n}{2000-0}; if\ 0 \le n \le 2000 \\ 0;\quad if\ n \ge 2000 \end{cases} \tag{10}$$

$$m_{f_{light_{weighted\_vehicle}}} = \begin{cases} 0;\quad if\ n \le 2000\ and\ y \ge 4000 \\ \frac{n-2000}{3250-2000};\quad if\ 2000 \le n \le 3250 \\ \frac{4000-n}{4000-3250};\quad if\ 3250 \le n \le 4000 \end{cases} \tag{11}$$

$$m_{fmedium\_weighted\_vehicle} = \begin{cases} 0;\quad if\ n \le 3500\ and\ n \ge 6000 \\ \frac{n-3500}{4250-3500};\quad if\ 3250 \le n \le 4250 \\ \frac{6000-n}{6000-4250};\quad if\ 4250 \le n \le 6000 \end{cases} \tag{12}$$

$$m_{fheavy\_weighted\_vehicle} = \begin{cases} \frac{n-8000}{8000-5000}; if\ 0 \le n \le 8000 \\ 0; if\ n \le 5000\ and\ n \ge 8000 \end{cases} \tag{13}$$

$$m_{fNO} = \begin{cases} \frac{0.5-n}{0.5-0}; if\ 0 \le n \le 0.5 \\ 0; if\ n \le 0\ and\ n \ge 0.5 \end{cases} \tag{14}$$

$$m_{fYES} = \begin{cases} \frac{n-1}{1-0}; if\ 0 \le n \le 1 \\ 0; if\ n \le 0\ and\ n \ge 1 \end{cases} \tag{15}$$

2.1.2 Fuzzy inference system for the in-park vehicle decision

The in-park vehicle decision considers two input variables, which are the tag number correspondence to the park slot number and the floor weight correspondence to the vehicle's weight type. The tag number correspondence for input 1 is shown in Figure 5, contains two membership functions, and has the same fuzzy criteria as the second input variable, as shown in Figure 6.

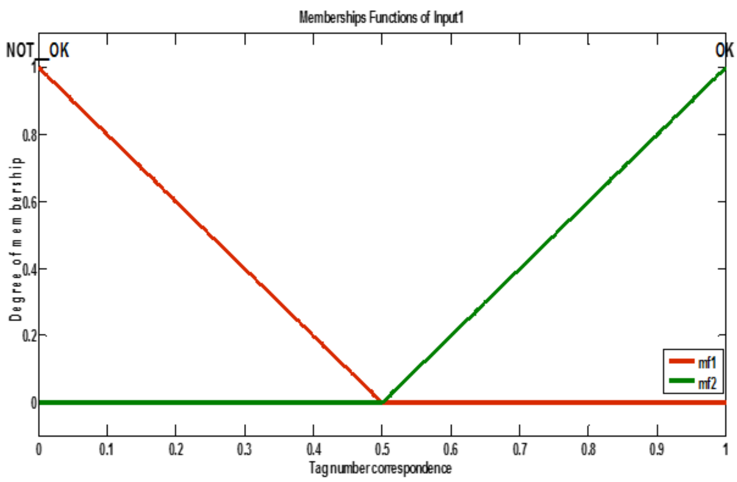

Figure 5: Input variable 1 for tag number correspondence with membership functions

The floor weight correspondence for input 2 contains two membership functions as shown in Figure 6, and the fuzzy criteria are shown in equations 16 and 17.

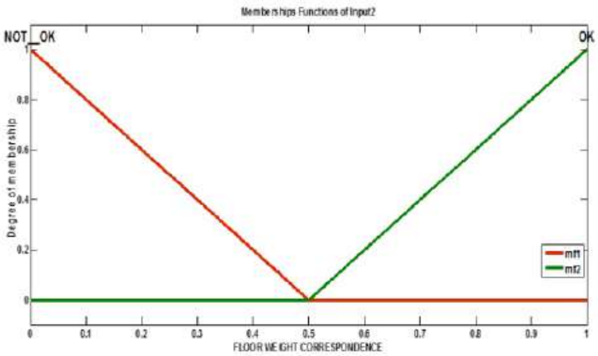

Figure 6: Input variable 2 for floor weight correspondence with membership functions

The output variable for entry state is the result of the decision for the inputs and its membership functions includes ENTRANCE_REMAINS_CLOSED and OPEN_ENTRANCE with range of 0 to 1 as described in figure 7.

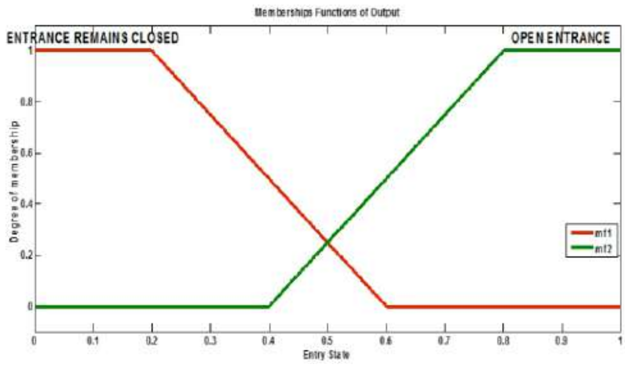

Figure 7: Output variable of in-park decision with membership functions

$$m_{fNOT\_OK} = \begin{cases} \frac{1-n}{1-0} \,; if\ 0 \le n \le 1 \\ 0\,; if\ n \ge 1 \end{cases} \qquad (16)$$

$$m_{fOK} = \begin{cases} \frac{n-1}{1-0} \,; if\ 0 \le n \le 1 \\ 0\,;\ if\ n \le 0\ and\ n \ge 1 \end{cases} \qquad (17)$$

3.0 RESULTS AND DISCUSSION

The results realized from the vehicle entry decision and the in-park entry decision are shown in Figures 8, 9, and 10. The horizontal axis shows the time axis, while the vertical axis represents the unit axis, which is a numerical value for both the vehicle entry, exit, and availability of parking lots. The results obtained provide information about the vehicle entry and exit based on the vehicle weights and the availability of parking lots for each vehicle.

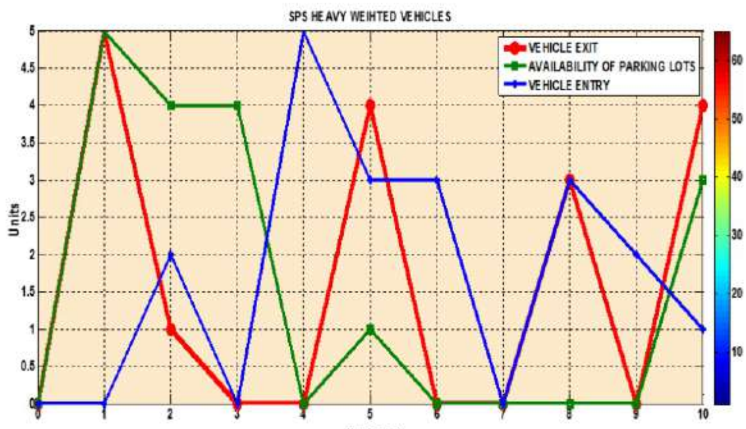

Figure 8: Plots showing vehicle entry, exit and availability of parking lots for heavy weighted vehicles

In Figure 8, when the availability of parking lots is in equilibrium, it is observed that there is a slight difference between the vehicle entry and vehicle exit each time a vehicle enters and leaves the smart system. For instance, the plot shows that when the heavy-weighted vehicle was at four minutes, the vehicle exits and the availability of parking lots were very small due to the large entry of vehicles, and as a result, the smart system denied access to other vehicles to keep the system in equilibrium. Also, when the vehicle was at six minutes, vehicle exit took place at zero units, vehicle entry at three units, and the availability of parking lots was at zero units.

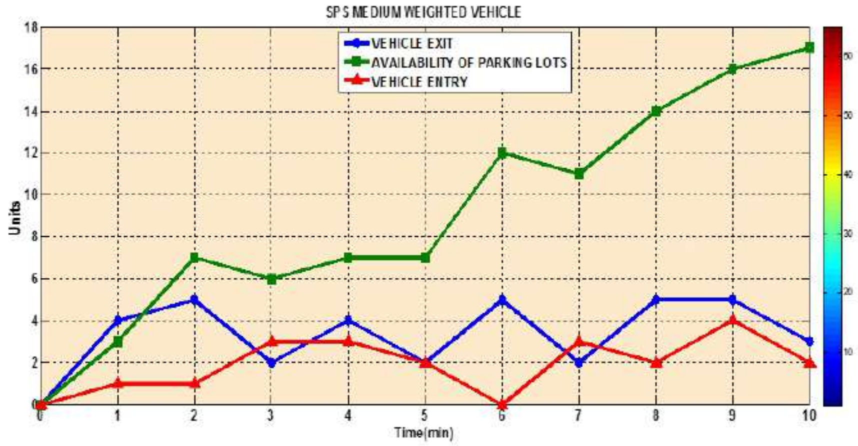

Figure 9: Plots showing vehicle entry, exit and availability of parking lots for medium weighted vehicles

In Figure 9, it is observed that the smart parking system ensures that the vehicle entry does not exceed the availability of parking lots because the vehicle exit is greater than the vehicle entry. For instance, when the vehicle was at nine minutes, vehicle exit occurred at five units, vehicle entry occurred at four units, and the availability of parking lots occurred at sixteen units.

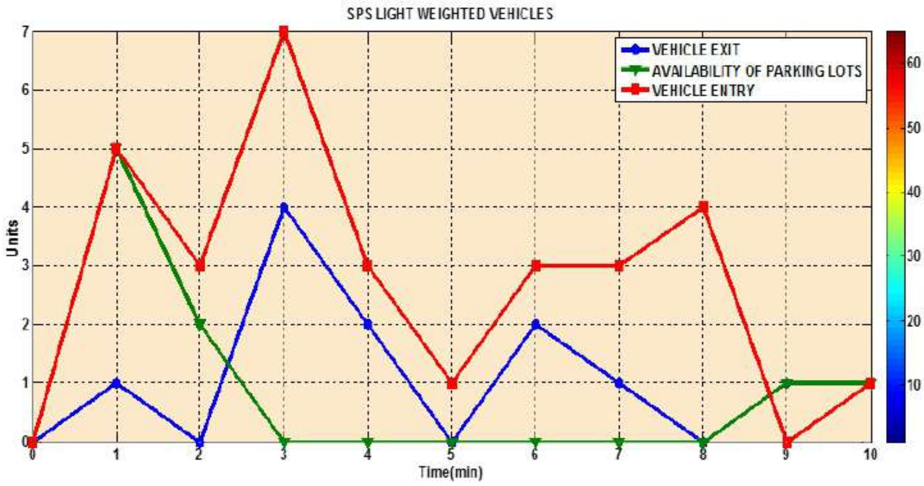

Figure 10: Plots showing vehicle entry, exit and availability of parking lots for light weighted vehicles

In Figure 10, it is observed that when the vehicle entry exceeds the vehicle exit, the availability of parking lots remains less until the vehicle exit exceeds the vehicle entry for light-weighted vehicles. For instance, when the vehicle was at four minutes, vehicle exit occurred at two units, vehicle entry occurred at three units, and the availability of parking lots remained at zero units. Also, when the vehicle was at eight minutes, vehicle exit took place at zero units, vehicle entry occurred at four units, and the availability of parking lots remained at zero units, which indicates that there was no space for packing lots.

4.0 CONCLUSION

To overcome the problems of parking vehicles on parking lots in some cities, the automatic vehicle smart parking system is the main idea in traffic, and this system can be controlled without human interference. The electronic data keeps information about the available number of parking lots using the transducer, and the transducer collects and posts records of the available parking lots for light, medium, and heavy-weighted vehicles once a parking lot is free. Vehicle detection at the entry can be achieved when using the weight transducer to detect when a vehicle tries to enter the park and when a vehicle leaves the park. The availability of the parking lot for a sensed-weighted vehicle depends on the presence of the RFID reader in different categories of vehicles.

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