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Optimization of Fuzzy Mathematical Model of Rectangular-Shaped Parking Space

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ABSTRACT

In the dynamic expansion of urban population, there arises a pressing need to establish well-defined parameters for parking spaces. The provision of parking plays a pivotal role in both residential complexes and commercial establishments. Ill-conceived roadside parking areas can result in severe traffic congestion, and at times, even lead to accidents. Different car sizes need different parking lot sizes. Therefore, given these factors, adaptable parking solutions have become imperative. Within the framework of the proposed research, the parking spaces in question are envisaged as rectangles, and a mathematical model has been devised within a fuzzy environment. Numerical examples are taken to illustrate the mathematical model. LINGO software is used to solve the mathematical model and MATLAB is used to define the fuzzy variable. At the outset the results will reveal the importance of making the length of the parking space in fuzzy environment.

1. INTRODUCTION

The designated parking area caters to both short-term and long-term vehicle storage. Among essential components of transportation infrastructure, parking lots feature prominently. The design of these lots is strategically orientated towards maximizing vehicle capacity and efficient utilization. Key determinants for optimizing parking space include dimensions, layout, angles, and accommodation for a range of vehicle sizes and types. Various vehicles necessitate tailored parking spaces and configurations. This study focuses specifically on different types and sizes of cars.

The parking angles under consideration will be denoted as and as illustrated in Figure 1. These angles represent widely utilized configurations in parking lot scenarios. The selection of parking angles holds a significant sway in the optimization of parking space.

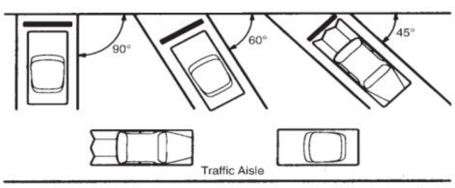

Figure 1. Parking angles

Different types of cars with different body types are given in Figure 2 and are available in the market. Most of the cars have the same breadth and different lengths. In Muscat, the parking lot size is fixed at 2.5m×5.5m. Dubai municipality fixed the parking lot dimension as 2.5m×5.0m [1], and Oman fixed the parking lot dimension for the Duqm city urban planning and development project as 2.5m×5.5m [2].

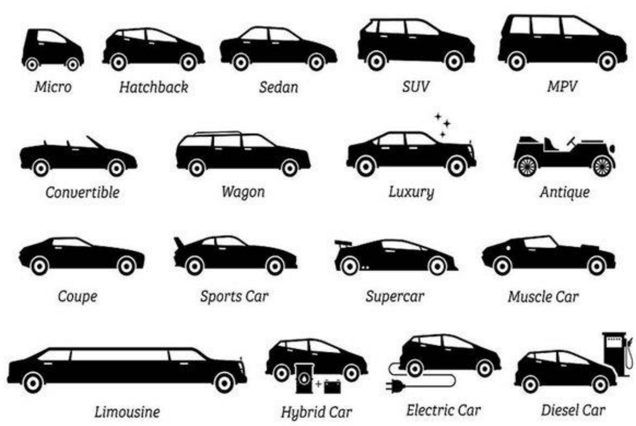

Figure 2. Different types of cars

Here the discussion arises about the length of the parking lot. Different countries follow parking lot dimensions for their own convenience. After the observation, it is understood that the countries fixed the breadth of the parking lot and compromising its length.

By reducing parking lot length, we will increase the number of parking lots in the allotted parking space. So, in this paper, the length of the parking lot will be considered a variable, and its lower and upper values are defined as 5.0m and 5.5m, respectively. With the use of sonar sensors, the car decides the turning angle, and with the use of fuzzy logic, the car can automatically decide the motion direction [3]. A cloud-based parking lot reservation system was created, and it will monitor the available parking lots for the cars. The time consumption and fuel consumption will be reduced by reserving the parking lot [4]. The availability of the parking lot and weight of the car are considered to decide the suitable parking lot to maintain the equilibrium of the parking space [5]. Most of the research papers focus on parking the cars in the suitable parking lot. A novel approach is taken in this paper to consider the parking lot length as a variable under a fuzzy environment to optimize the number of parking lots in the available parking space.

In this paper, the mathematical model for rectangular parking spaces is taken under a fuzzy environment. The length of the parking lot is taken as a fuzzy variable. Also, three different parking lot dimensions are taken into consideration for a numerical example. It is denoted as follows: Dimension 1 (DM1: 2.5m×5.0m), Dimension 2 (DM2: 2.5m×5.25m), and Dimension 3 (DM3: 2.5m×5.5m).

2. LITERATURE REVIEW

Less parking space, vehicle traffic, building infrastructure, and more factors will influence the traffic in crowded cities. So, the drivers will face difficulties in parking the vehicles. A fuzzy logic was taken in developing the smart parking space. The number of unoccupied parking lots in various locations inside the cities, the distance between the vehicle and the unoccupied parking lots, and the location traffic information will be provided to the drivers [6].

The automated steering controller was designed and tested using MATLAB Simulink [7]. A* algorithm and entropy methods are taken in the process of optimizing the parking space with the shortest path to unoccupied parking lots [8]. An autonomous system to park the car in the unoccupied parking lot was designed and simulated by using MATLAB Simulink software and fuzzy logic [9].

Small parking spaces inside the shopping complex are considered, and smart parking spaces are developed. In the shopping complex, the number of floors can be increased in the future, and at the same time, parking lots can also be increased by constructing floors for parking a greater number of cars. The software Arduino, RFID, fuzzy logic, and MATLAB Simulink are used in developing the smart parking spaces [10].

The proximity of the cars identified and the suitable parking lots will be assigned to the waiting cars using the parking control system, and fuzzy logic was used to calculate the distance between the vehicles [11]. Steering controller and speed controller are defined under fuzzy environment. A kinetic model was developed for the autonomous parking system [12]. To increase the performance quality, fuzzy logic was used in parking lot operator problems in electric vehicle charging stations [13]. In the less amount of time to find the appropriate parking lot, the fuzzy logic controller was used [14]. Fuzzy logic inference is adopted to develop a mathematical inference, and the inference was used to balance the parking lot allotment and traffic situation to reach the parking space [15]. An application for an automated vehicle parking system was created with a PIC 16F84A microcontroller and fuzzy logic. Based on data from infrared sensors, this system has the ability to seek out parking spaces, reverse, and park itself there [16].

3. MATHEMATICAL MODEL

The pictorial representation of the proposed parking space is given below in Figure 3.

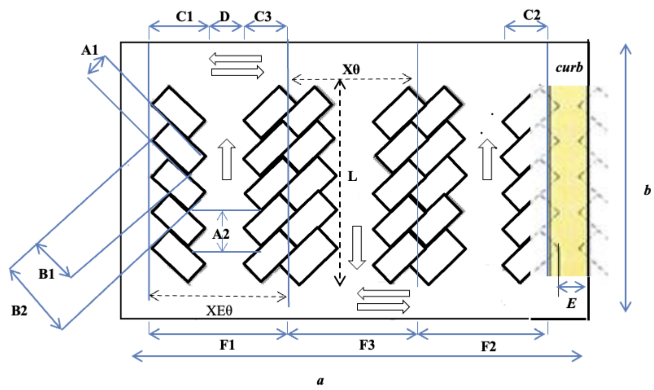

Figure 3. Parking lot design

3.1 Assumptions

To achieve the proposed parking lot design given in Figure 3, the below assumptions are made:

(1) One-way traffic across the aisles;
(2) Two-way traffic perpendicular to the rows;
(3) Both sides of the parking space will have two entries/exits;
(4) At the adjacent to the wall, no exterior rows are allowed.

The assumption (2) can be taken as one-way traffic perpendicular to the rows, and assumption (4) can be taken as the exterior rows are adjacent to the wall according to the parking lot design taken.

The objective function and constraints of the proposed mathematical model are given below. The length of the parking lot is considered a fuzzy environment.

3.2 Objective function

The objective of the proposed mathematical model of the rectangular parking space is to maximize the number of cars in the allotted parking space. With the constraints like space, parking lot dimensions, and parking angles. The objective function is defined in Eq. (1)

$$Max\,\tilde{z} = \sum_{\theta=0^\circ,45^\circ,60^\circ,90^\circ} (N\theta + NE\theta) \quad (1)$$

3.3 Constraints

Eq. (2) discussed that the sum of the lengths of the number of cars in the interior row and the exterior row should not be more than the length of the parking space.

$$\sum_{\theta=0^{\circ},45^{\circ},60^{\circ},90^{\circ}} (F3X\theta+(D+C1)XE\theta) \leq a \tag{2}$$

Eq. (3) discussed that the total number of outside rows should be less than or equal to two.

$$\sum_{\theta=0^{\circ},45^{\circ},60^{\circ},90^{\circ}} XE\theta \leq 2 \tag{3}$$

For $\theta = 0°, 45°, 60°, 90°$.

Eq. (4) discussed that the area allotted for inside rows should be completely occupied by the number of parking lots allotted in the inside rows. The value of L [17] can be calculated by $L = b - 2 * 7$.

$$A2N\theta - 2L \cdot X\theta \leq 0 \tag{4}$$

Eq. (5) discussed that the area allotted for outside rows should be completely occupied by the number of parking lots allotted in the outside rows.

$$A2NE\theta - L \cdot XE\theta \leq 0 \tag{5}$$

Eq. (6) discussed the non-negativity conditions of decision variables.

$$N\theta, X\theta, NE\theta, XE\theta \geq 0 \tag{6}$$

3.4 Decision variables

The decision variables of the proposed mathematical model of rectangular shaped parking spaces are given below:

$N\theta$ number of cars with θ angle inside row;
$NE\theta$ number of cars with θ angle outside row;
$X\theta$ number of inside rows with θ angle;
$XE\theta$ number of outside rows with θ angle.

4. NUMERICAL EXAMPLE

Table 1. Input values (for 0 and 45 degrees)

	Angled Parking Degrees					
	0			45		
Symbol	**DM1**	**DM2**	**DM3**	**DM1**	**DM2**	**DM3**
a	120	120	120	120	120	120
b	80	80	80	80	80	80
A1	6.50	6.50	6.50	2.50	2.50	2.50
A2	6.50	6.50	6.50	3.54	3.57	3.60
B1	2.50	2.50	2.50	5.00	5.25	5.50
B2	6.50	6.50	6.50	6.80	6.95	7.10
C1	2.50	2.50	2.50	5.30	5.45	5.60
C2	2.50	2.50	2.50	4.70	4.85	5.00
C3	2.50	2.50	2.50	4.40	4.60	4.70
D	3.00	3.00	3.00	3.75	3.75	3.75
E	0.00	0.00	0.00	0.60	0.60	0.60
F1	8.00	8.00	8.00	13.45	13.80	14.05
F2	8.00	8.00	8.00	12.85	13.20	13.45
F3	8.00	8.00	8.00	12.55	12.95	13.15

Table 2. Input values (for 60 and 90 degrees)

	Angled Parking Degrees					
	60			90		
Symbol	**DM1**	**DM2**	**DM3**	**DM1**	**DM2**	**DM3**
a	120	120	120	120	120	120
b	80	80	80	80	80	80
A1	2.50	2.50	2.50	2.50	2.50	2.50
A2	2.89	2.90	2.91	2.50	2.50	2.50
B1	5.00	5.25	5.50	5.00	5.25	5.50
B2	6.25	6.43	6.60	5.00	5.25	5.50
C1	5.60	5.80	6.00	5.00	5.25	5.50
C2	4.90	5.10	5.30	4.25	4.50	4.75
C3	5.05	5.30	5.50	5.00	5.25	5.50
D	4.50	4.50	4.50	7.00	7.00	7.00
E	0.70	0.70	0.70	0.75	0.75	0.75
F1	15.15	15.60	16.00	17.00	17.50	18.00
F2	14.45	14.90	15.30	16.25	16.75	17.25
F3	14.60	15.10	15.50	17.00	17.50	18.00

To illustrate the mathematical model, the numerical example has been taken.

4.1 Input values

The standard parking lot dimensions [2] are defined for the three different dimensions DM1, DM2, and DM3. Also, given it as input values for the proposed mathematical model as shown in Table 1 and Table 2.

5. RESULTS

The numerical example is solved by using LINGO software and results are presented in Table 3.

From the results in Table 3, it is perceived that the change in the length of the parking lot will affect inversely proportional to the number of cars. The output values given in Figure 4 only for the length of the parking lot as 5.0m, 5.25m and 5.5m.

Table 3. LINGO results of the mathematical model

Dimensions	**DM1 (2.5m×5.0m)**	**DM2 (2.5m×5.25m)**	**DM3 (2.5m×5.5m)**
Objective value	371	355	347
Variable	Value	Value	Value
N0	0	0	0
NE0	0	0	0
N45	0	0	0
NE45	0	0	0
N60	319	91	136
NE60	0	0	0
N90	52	264	211
NE90	0	0	0
X0	0	0	0
XE0	0	0	0
X45	0	0	0
XE45	0	0	0
X60	7	2	3
XE60	0	0	0
X90	1	5	4
XE90	0	0	0

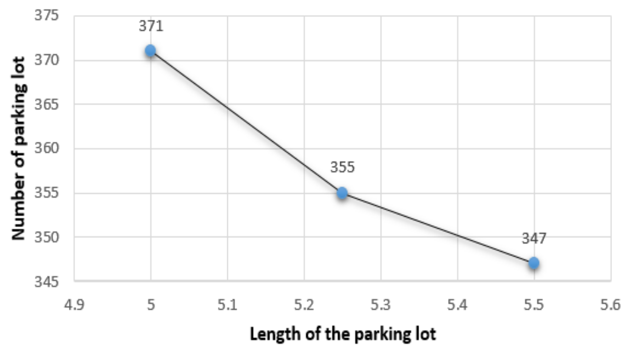

Figure 4. Graph of the LINGO results

To find the fruitful results of the mathematical model, the more lengths of the parking lot need to be considered, and the output results need to be represented as a graph and equation. To develop more input values for the different lengths of parking lots, it is recommended to define a forecast graph by using the available output results. The forecast results graph and its equation are given in Figure 5 below, and the forecast result is given in Table 4.

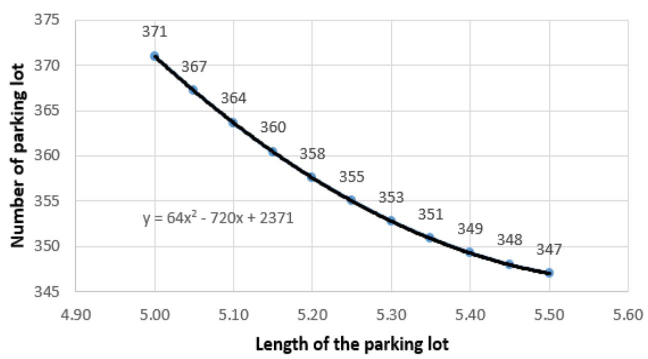

Figure 5. Forecast results graph and its equation

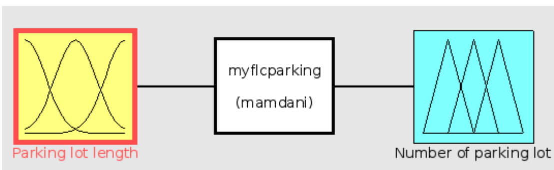

Figure 6. Fuzzy rules with one input and one output

5.1 Fuzzy logic controller

A fuzzy model is a mathematical representation that uses fuzzy sets to handle uncertainty. It is made up of parameters like membership functions, which establish an element's level of set membership, and rules, which specify how inputs are translated into outputs. Membership functions can be designed to capture various degrees of fuzziness, such as Gaussian, trapezoidal, or triangular functions. In a fuzzy logic system, rules specify how inputs are processed to produce an output. These rules are commonly stated as "if-then" statements.

The length of the parking lot is taken under a fuzzy environment, and its extreme values are taken as a minimum of 5.0m and a maximum of 5.5m. The fuzzy logic controller is developed based on Mamdani rules with one input and one output, as given in Figure 6. The length of the parking lot is the input value, and the number of parking lots will be the output value. A triangular fuzzy number is considered, and the membership function for the proposed problem is given below:

5.1.1 Membership function

In the proposed mathematical model, the triangular fuzzy number is taken into consideration, and it is defined in Eq. (7). Length of the parking lot considered under fuzzy environment. The minimum parking lot length is taken as 5.0m, and the maximum length is taken as 5.5m. And the graph of the membership function for the triangular fuzzy number $\tilde{B}_1 = (5.0, 5.25, 5.5)$ is presented in Figure 7.

$$\mu_{\tilde{B}_1}(x) = \begin{cases} 0, & x \le 5 \\ \dfrac{x-5}{5.25-5}, & 5 \le x \le 5.25 \\ \dfrac{5.5-x}{5.5-5.25}, & 5.25 \le x \le 5.5 \\ 0, & x \ge 5.5 \end{cases} \tag{7}$$

As per the results of the proposed mathematical model, the triangular membership function is the suitable fuzzy rule [18, 19]. Using MATLAB, the membership function for the parking lot length is defined. According to the prescribed parking lot dimensions, the minimum and maximum values of parking lot length are given as 5.0m and 5.5m, respectively. Hence, the membership function for the input value of parking lot length is developed with a minimum value of 5m and a maximum value of 5.5m, and it is given in Figure 8.

The increment or decrement in the parking lot length will affect the number of parking lots inversely proportional. In considering this aspect, using MATLAB, the membership function of the number of parking lots is designed. Hence, the membership function plot for the output variable "Number of parking lots" is developed with a minimum of 347 and a maximum of 371 parking lots, and it is presented in Figure 9.

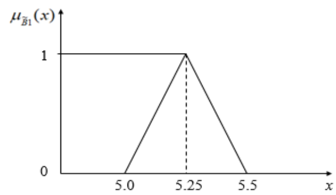

Figure 7. Membership function graph

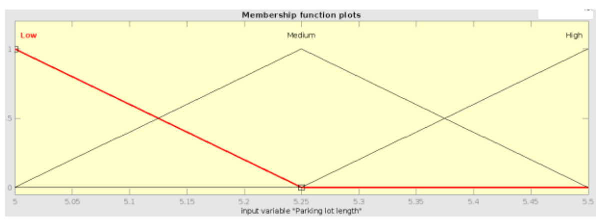

Figure 8. Membership function for input variable

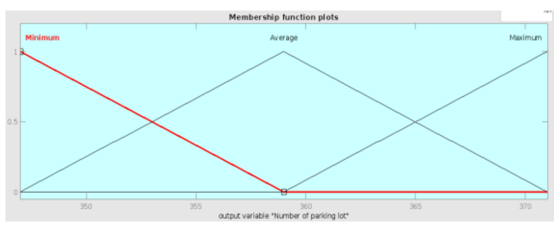

Figure 9. Membership function for output variable

It is obvious that if the length of the parking lot is increased, then the number of parking lots will decrease and vice versa. In the results, it is observed that if-then approach. Hence, the rules of fuzzy logic controllers are developed to fulfil this nature.

Rules of fuzzy logic controller are developed and presented below:

If (Parking lot length is low), then (Number of parking lots is maximum);

If (Parking lot length is medium), then (Number of parking lots is average);

If (Parking lot length is high), then (Number of parking lots is minimum).

The developed fuzzy logic controller is executed for different input values for parking lot lengths of 5m, 5.25m, and 5.5m, and the results are presented in Figures 10-12, respectively.

Surface view of the fuzzy results given in Figure 13.

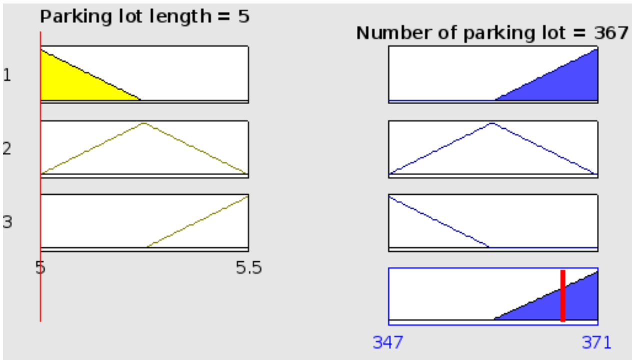

Figure 10. Output value for the input value parking lot length (5m)

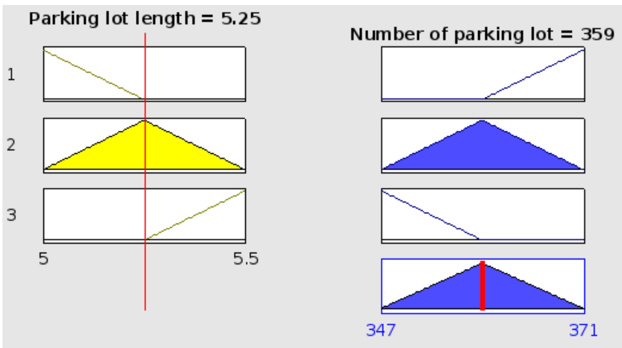

Figure 11. Output value for the input value parking lot length (5.25m)

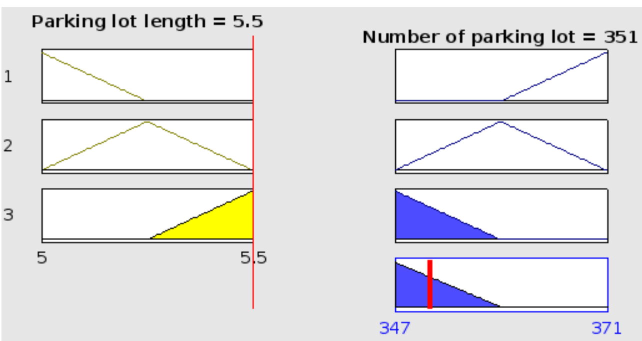

Figure 12. Output value for the input value parking lot length (5.5m)

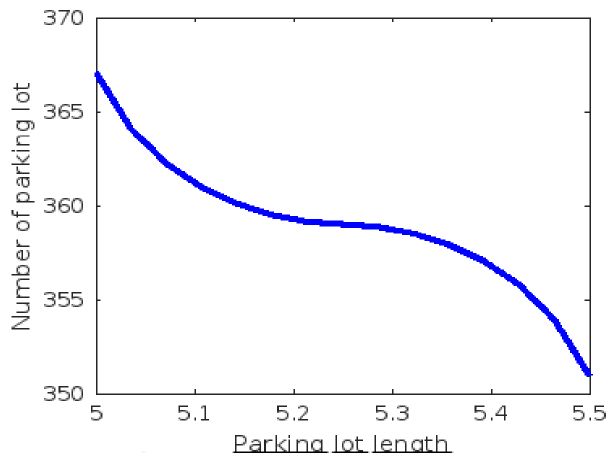

Figure 13. Surface view of the fuzzy results

In Table 4, the results of the proposed mathematical model for different values of length of the parking lot are given. Using LINGO software, the numerical example was solved. MATLAB results and forecast graph results are prepared based on the results obtained using Lingo software.

Table 4. Results of the mathematical model

Length of the Parking Lot	MATLAB Results	Forecast Graph Results	LINGO Results
5.00	367	371	371
5.05	363	367	-
5.10	361	364	-
5.15	360	360	-
5.20	359	358	-
5.25	359	355	355
5.30	359	353	-
5.35	358	351	-
5.40	357	349	-
5.45	355	348	-
5.50	351	347	347

5.2 Sensitivity analysis

The results of the mathematical model using LINGO software are compared with the forecast graph and MATLAB results in Table 4, and they are presented in Figure 14. It shows the sensitivity of the results obtained from MATLAB, Excel solver, and LINGO. The forecast graph is developed from the LINGO results. Fuzzy Inference System (FIS) is created from the LINGO results, and the results are obtained by executing the FIS.

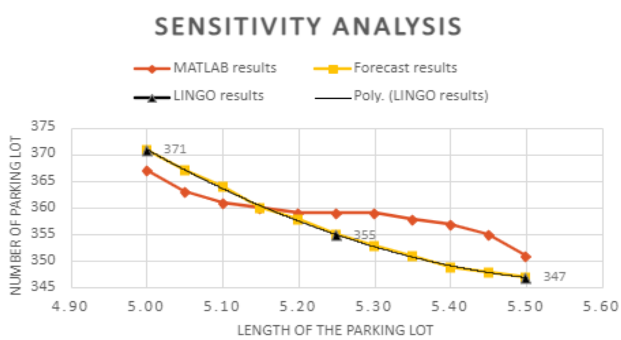

Figure 14. Graphical sensitivity analysis

MATLAB results, forecast graphs, and LINGO results are independent of each other. So, the pictorial sensitivity analysis to compare the results with respect to the different parking lot lengths was done in Figure 14. In Figure 14, there is not much difference between the results. Hence, it is recommended that using MATLAB we can predict the results without solving the problem by using LINGO software for all values of parking lot length. Also, using MATLAB software will reduce the working labour time, and it will be easy to choose the value for parking lot length.

6. DISCUSSION

Effective utilization of parking space is playing a pivotal role in the preparation of parking lot design. At the same time, there should not be more parking lots in a small congested area. The number of parking lots should be optimal. It should not affect the traffic, and it should also have an optimum number of parking lots. From Table 4, it is perceived that different values of length of parking lot will result in different numbers of parking lots. In this case, the number of parking lots will increase proportionately if the length of the parking lot decreases. The efficient use of parking space will be impacted by the increment in parking lots. Hence, using MATLAB results, we can predict the number of parking lots related to the length of the parking lot.

7. CASE STUDY

To demonstrate the practical value of the proposed model, the below real-world problem is taken. Using Google Maps, Figure 15 was taken, and the length and breadth of the parking space were also measured by using Google Maps. Total number of parking lots is 84. The length of the parking space is approximately 73m (=a) given in Figure 16, and the breadth of the parking space is approximately 43m (=b) given in Figure 17.

Total 84 parking lots allotted with the approximate dimension of 2.5m×6.8m. The length and breadth of the parking space will be taken as input values for the proposed mathematical model along with the input values given in Tables 1 and 2. The proposed model is solved by using MATLAB, Excel solver and LINGO software. And the result is presented in Table 5.

In the actual parking lot design, more space is taken for the parking lot dimension (2.5m×6.8m); refer to Figures 18 and 19. So, the number of parking lots was only 84. If the space utilisation concepts are applied, then there will be the possibility for more parking lots in the same parking space.

Figure 15. Parking space

Figure 16. Length of the parking space

Figure 17. Breadth of the parking space

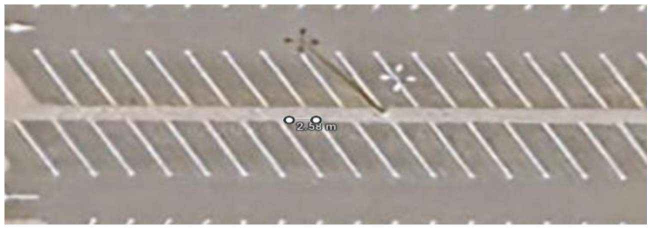

Figure 18. Breadth of the parking lot

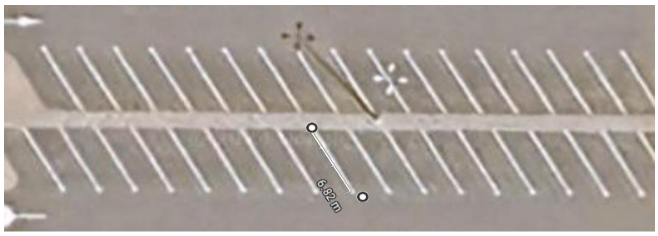

Figure 19. Length of the parking lot

Table 5. Results of the mathematical model (Case Study)

Length of the Parking Lot	MATLAB Results	Forecast Graph Results	LINGO Results
5.00	100	100	100
5.05	98	98	-
5.10	97	96	-
5.15	97	94	-
5.20	94	93	-
5.25	92	92	92
5.30	94	91	-
5.35	92	91	-
5.40	92	91	-
5.45	92	91	-
5.50	91	91	91

7.1 Sensitivity analysis

Figure 20 depicts the sensitivity of the results obtained from different tools like MATLAB, Excel Solver, and LINGO. The forecast graph is developed by using the LINGO results. MATLAB results are obtained from the Fuzzy Inference System (FIS).

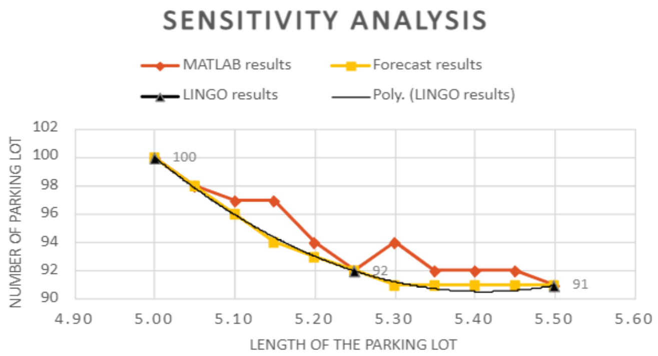

Figure 20. Graphical sensitivity analysis (Case Study)

8. CONCLUSION

The mathematical model of rectangular-shaped parking spaces is defined and developed in a fuzzy environment. The length of the parking lot is taken as a fuzzy variable. And for problem solving, only three values-5.0m, 5.25m, and 5.5m, respectively-are taken as the input values for the length of the parking lot. LINGO software is used to solve the numerical example of the proposed mathematical model. The LINGO results of the proposed mathematical model are used to develop the forecast graph and fuzzy logic controller in MATLAB. All the results are compared to check the effectiveness of the mathematical model. At the outset, from the results, it is perceived that the number of cars increases when the length of the parking lot is reduced. Fuzzifying parking lot length will reduce the labour time to calculate the number of parking lots for different lengths of the parking lot length. LINGO results substantiate the effectiveness of the changes in the length of the parking lot. Whether it is Dubai or Oman, the parking lot dimension is adjustable now. Hence, parking lot dimensions can be fixed based on the available area and to meet the expectations of the management. In the future, more input values can be calculated for the different lengths of the parking lot to achieve more accurate and exact results.

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NOTATIONS

a	Length of the rectangle
b	Breadth of the rectangle
A1	Bay width
A2	Bay width, parallel to aisle
B1	Bay length
B2	Length of line between bays
C1	Bay depth to wall
C2	Bay depth to curb
C3	Bay depth to interlock
D	Aisle width between bay lines
E	Bumper overhang (typical)
F1	Module, wall to interlock
F2	Module, curb to interlock
F3	Module interlock to interlock