Proposal for automatic valet parking using learning function

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Abstract

Automatic valet parking using learning function is proposed in this study. The number plate (vehicle registration plate or license plate) of each vehicle is read using a camera when entering and leaving the parking lot. The entering and leaving date and time of each vehicle can be searched by using the plate characters. An image recognition technic and a timer function are used at this time. The license plates are stored in a database. When a customer is entering the parking lot, the reception number and the customer's vehicle plate number are stored on a magnetic card and handed over it to the customer. When leaving the parking lot, the customer goes to the exit and inserts the magnetic card, and the driver completes the payment process. It is the time when the leaving process is completed. The entering date and time and the leaving date and time are stored together in the database. It is important to shorten the time (leaving time) obtained by subtracting the requested leaving time from the actual leaving date and time in the automated valet parking. The patterns and characteristics of users can be extracted through a data-mining technique by utilizing the created database. Some new values can be added based on the characteristics of the customer's car using this system. These will enable the functionality and efficiency of the system to be improved. For example, if it is known that a registered customer's vehicle tends to stay parked there all day after entering the parking lot, the system will park the vehicle in a farthest location from the exit (a location with the lowest priority), allowing other vehicles to leave smoothly. The priority can be given to other vehicles. The vehicles that tend to leave the parking lot in a short time are conversely parked in the highest priority location (closest to the exit). This process can improve the time efficiency of leaving. When the leaving date and time of a vehicle can be known in advance, it can be moved closer to the exit and the time to leave can be shortened. In this study, a simulation system is constructed to improve the efficiency of automated valet parking using the above-mentioned learning function.

Key words
multi-story parking lot, learning function, automated valet parking, leaving time, entering time

1. Introduction

In recent years, some research has been conducted into the future of multi-story parking lots with the evolution of autonomous vehicles and the automated valet parking is attracting attention (Kitagawa Corporation, 2021). It is a parking lot system where vehicles can enter and leave automatically. There is another paper on automated valet parking in addition to the papers published by the authors of this paper (Yamamoto et al., 2023). The entire parking lot is divided into a spatiotemporal grid in the paper and it proposes a system that determines the optimal vehicle route to avoid collisions and congestion, and arrive at the destination. However, the proposal cannot be applied to all vehicles. The main reason for this is that customer vehicles are all different (they are diverse and differ in performance, shape and size, etc.), and it becomes impossible to provide universal control. In contrast, the automated valet parking system proposed in this paper introduces a special flat system for transporting vehicles which is called a cell pallet. This allows the use for any vehicle. The parking issues are also important in Japan's Smart City Concept (NEC, 2022). Many challenges arise as the scale of parking structures increases, for example accidents (traffic accidents and theft, etc.), searching for a parking space, use in narrow boarding and disembarking areas and difficulty in use for beginners and the elderly. An automated valet parking system using a unique automated pallet to solve these problems was proposed (Funase et al., 2022a), and a method for determining parking locations with efficient leaving time was also proposed (Funase et al., 2022b). Furthermore, an automated pallet movement method was proposed to improve the leaving time efficiency (Funase et al., 2022c), and it clarified that the time efficiency could be improved (Funase et al., 2023a). The structure of the multi-story parking lot that is the subject of this study was proposed in a previous paper (Funase et al., 2022c) that makes maximum use of the three-dimensional space. In addition, a previous paper was the first to present the basic entering and leaving algorithms for this multi-story parking lot (Funase et al., 2024). The improvement measures were also proposed (Okada et al., 2024a). The multi-story parking lot covered in those papers is mechanical multi-story parking lot equipped with one elevator dedicated to entry and one elevator dedicated to exit (Funase et al., 2022a; Funase et al., 2022b; Funase et al., 2022c; Funase et al., 2023a; Funase et al., 2023b; Funase et al., 2024; Okada et al., 2024a).

Also, a paper has been published that examined three methods to speed up automated valet parking (Okada et al., 2024b).

The demand for automated valet parking systems is growing due to the expectations of improving the efficiency of parking lots in urban areas and enhancing convenience for users. Traditional parking systems have been designed to simply assign parking spaces to vehicles that enter the parking lot. These systems have some issues with efficient vehicle management and rapid leaving response of the vehicle. A future parking system is necessary to understand (learn) the characteristics of the entered vehicles to use the parking lots and optimize the allocation of parking spaces.

The following papers regarding AVP (automated valet parking) based on machine learning have been published.

- AVP where the vehicle moves and parks by itself (Khalid et al., 2021); The vehicle can automatically park in an available parking space using the system utilizing sensors in the vehicle and parking lot.
- AVP where the parking lot system can transport the customer's vehicle (Funase et al., 2023a); The mechanical parking system that utilizes the pallets and lifts to automatically move and store the vehicles.
- AVP using cloud and V2X (vehicle to everything) communication systems (Takacs and Haidegger, 2024); The system that efficiently guides multiple vehicles using cloud servers and V2X system.
- AVP where a robot can assist the vehicle transport (Atheef et al., 2024); The system in which a robot lifts a vehicle and transports it to a designated parking space.

The improvement of parking efficiency due to utilizing learning functions is the aim of this paper. Specifically, the vehicles that tend to park for long periods of time are parked farther from the exit and other vehicles to exit have priorities and the system can relieve traffic congestion in the parking lot as a whole. In addition, the vehicles that tend to leave the lot in a short time can be allocated near the exit to make leaving time more efficient. Furthermore, if the leaving time can be determined in advance, further efficiency can be achieved by moving the vehicle closer to the exit at that time. Incorporating these learning functions will improve the operational efficiency of the parking lot and increase user satisfaction. The effectiveness of those learning functions through simulations is considered in this paper.

2. Multi-story parking

The targeting of multi-story parking is made up of a skeleton of poles resembling a jungle gym. A cell pallet carrying the customer's vehicle can move left and right, up and down, and back and forth within the skeleton (Funase et al., 2022c). It is assumed that the entrance of the multi-story parking is next to the parking position on the left side of the first floor in the front row, and the exit is next to the parking spot on the right side of the first floor in the front row.

The driver can be checked in at the entrance to the parking, and given a magnetic card with an ID number printed on it. A camera is installed at the entrance to capture the driver's facial image and the license plate number of the vehicle. The data of the plate number and the facial image are input into a database along with the date and time of entering and the ID number. After that, the customer's vehicle is placed on a cell pallet and moved to the coordinates (1, 1, 1). The ID number is then associated with a number that indicates the parking location. The ID number is also associated with the parking location number indicating the parking location. The cell pallet containing the customer's vehicle is moved from coordinates (1, 1, 1) to the parking position (coordinates (x, y, z)) according to the entering algorithm. The parking location number is a consecutive number assigned to each parking location from the first floor to the top floor. The parking location (spot) number on the floor directly above parking spot No. j is $m_1m_3 + j$. For example, the parking position numbers are assigned as shown in Figure 1 in the case of the first floor. However, in the left-most column, it is not allowed to park in the position at coordinates (1, i, 1) ($i = 1, 2, \ldots, m_2$) in order to ensure that the cell pallet passes through. m_1 is the number of parking spots per row and m_2 is the number of spots on the top floor. m_3 is the number of parking spots per row. m_2

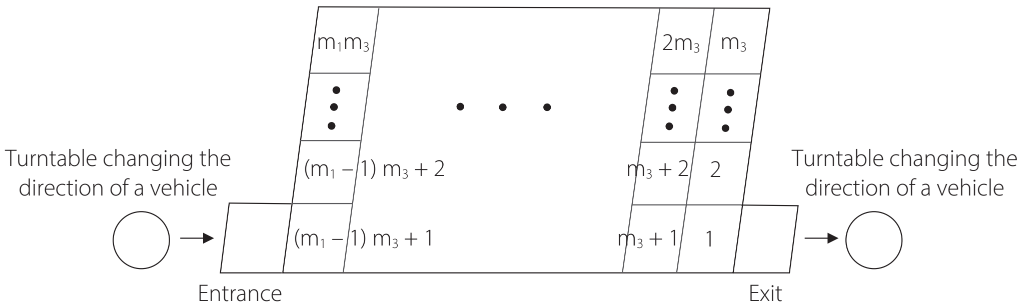

Figure 1: Parking spot number on the first floor
Source: Okada et al. (2024a).

floor and (m_2 – 1) floor are used as cell pallet passages and evacuation areas.

The customer goes directly to the exit when leaving the parking, and completes the leaving procedure by entering the magnetic card on which the ID number is printed. The customers' vehicle is controlled by the vehicle's number plate characters. For each character on the number (license) plate, the date and time of entering, the time of the request for leaving, the date and time of leaving, and the leaving time for each customer's vehicle are input into a database within the system. The parking location number is calculated using the ID number, and the cell pallet parked at the corresponding coordinates is moved to coordinates (m_1, 1, 1). Here, the leaving time is the time from the request time for leaving (the time when the process, etc. is completed) until the target cell pallet arrives at the coordinates (m_1, 1, 1) and the customer's vehicle has reached the exit. In other words, it is the time obtained by subtracting the time of the leaving request from the leaving date and time.

3. Entering algorithm

Identifying the vehicles that have patterns in their departure times, parking times, etc. is discussed in Chapter 6. Okada's method (Okada et al., 2024 a) is used for vehicles with no regularity (no pattern), which was mentioned in Section 4.2 (2). Namely, the parking position for entering vehicles is determined in ascending order of parking position number in the available parking spaces.

4. Leaving algorithm

The basic leaving algorithm is shown below. For the coordinates (x*, y*, z*) corresponding to the parking position of the cell pallet containing the vehicle requested to leave, the cell pallet parked at the coordinates (x*, t, z*) (t = y* + 1, y* + 2, . . ., ω) (ω is the top floor on which the cell pallet is parked) is moved to the (ω+1) floor, etc. And, the cell pallet parked at coordinates (x*, y*, z*) is moved to coordinates (x*, m_2, z*). Subsequently, the moved (evacuated) cell pallet is returned to the original position. Then the cell pallet parked at coordinates (m_1, t, 1) (t = 1, 2, . . ., ω) is evacuated to the (ω + 1) floor, etc. The cell pallet (coordinates (x*, m_2, z*)) containing the vehicle requested to leave is moved to coordinates (m_1, 1, 1), and the vehicle requested to leave is moved to the exit. Then, the evacuated cell pallet is returned to its original position.

5. Used learning function

It is important to clarify how much the leaving time can be improved by adding the following learning functions. Some simulations are used in this paper.

(1) If it is found from the characters in the vehicle license plate that a customer who enters the entrance has a tendency to park there for a whole day each time, or if the vehicle of the customer is staying at a hotel or other lodging facility and the number of days is to be parked is known in advance, it is parked in a place far from the exit (a place with the lowest priority). This process allows other vehicles to leave more smoothly. In addition, the time to leave the parking lot is predicted from past data, and the vehicle is moved to a parking position closer to the exit before that time. Thereby the leaving time becomes shorter. [Prediction of leaving time when parking period is long]

(2) Conversely, for vehicles that tend to leave the parking lot in a short time, the time efficiency of leaving the parking lot can be improved by parking the vehicle in the parking position (coordinates (m_1, t, 2)) closest to the exit in the order of t = 1, 2, . . ., ω*. The cell pallet parked at coordinates (m1, t* + 1, 2) is moved sequentially to the vacant coordinates (m_1, t*, 2) when a vehicle parked at coordinates (m_1, t*, 2) leaves the parking lot. This procedure is repeated until t* = ω* – 1. [Prediction of leaving time when parking period is short]

(3) If the leaving time can be specified (for example, after m hours), the vehicle is moved closer to the exit β hours before and the leaving time can be shortened. This is the same type of learning function as (1), and it requires highly accurate prediction of leaving time in a short period of time. [Prediction of typical parking period and leaving time]

6. Establishment of learning function

The common points between the 'learning functions' mentioned above and the learning functions described in this chapter are as follows. The system determines the temporary parking location of the cell pallet containing the customer's vehicle from the characters in the vehicle's license plate, and the cell pallet is moved to the coordinates (m_1, 1, 1) and the customer's vehicle is moved to the exit when a request is made to leave the parking lot. The information on which the learning function is based is as follows: characters of the customer vehicle's license plate number, ID number, cell pallet parking position number, time of request for leaving, and time when the condition for leaving is completed. In addition, if the ID number card is lost, a facial image of the driver taken at entering the parking lot will be used. [Achieving process of the learning function]

(1) A camera reads the characters on the customer's license plate and takes an image of the driver's face.

(2) In each learning function, if the characters of the license plate of the corresponding vehicle is registered, proceed to operation (7). Otherwise, proceed to operation (3).

(3) The entering process is performed using the entering

algorithm described in Chapter 3.
(4) When there is a leaving request, the leaving process is performed using the algorithm described in Chapter 4.
(5) The leaving time is calculated by subtracting the leaving time from the requested leaving time, and it is checked whether any of the learning functions mentioned in Chapter 5 can be applied to the system.
(6) Proceed to (11).
(7) In the case of Chapter 5 (1), the vehicles will be parked in order starting from the rear-most parking spot number.
(8) If the conditions in Chapter 5 (2) are satisfied, the vehicles will be parked in the order of parking positions 1, 2, 3 . . . At that time, the cell pallets that were originally in parking space numbers. 1, 2, 3, . . . are moved to the lowest (smallest) parking space number among the available parking spaces.
(9) If the condition in Chapter 5 (3) can be applied, the vehicle will first enter the parking space with the lowest available parking space number. Then, the parking position is replaced with parking position No. 1 at the time predicted from experience (for example, 15 minutes before).
(10) The leaving process is performed using the leaving algorithm described in Chapter 4 when there is a leaving request.
(11) Finish the process.

7. Simulation

In the 'Establishment of learning function' mentioned in Chapter 6, the time cost of performing operations (1) and (2) for each vehicle entering the parking is instantaneous compared to the time it takes to move the cell pallet (time to enter the parking lot, time to leave the parking lot), and the time is therefore negligible. In this study, the travel time is calculated by multiplying the travel distance of the cell pallet by a unit time (Funase et al., 2024). The flowchart for calculating the entering time per vehicle is shown in Figure 2. The chart can derive the total travel distance.

Next, the flowchart for determining the leaving time when the target learning function is feasible, and when none of the learning functions can be realized, is shown in Figure 3. However, the number of the feasible learning function is added to the cell pallet. If a cell pallet becomes an empty space due to the leaving of a vehicle, it is automatically filled. The final entering position (coordinate) of the cell pallet for each learning function is shown in Figure 4.

The entering time of the cell pallet for each learning function is the distance up to the four patterns as shown in Figure 4. In addition, the leaving time of the cell pallet for each learning function is the distance from each of the four patterns in Figure 4 to the coordinate (m_1, 1, 1). The movements for the entering and leaving of each vehicle are shown in Figure 5 when there are the corresponding learning functions.

8. Experimental

The entering and leaving times were calculated respectively for ten vehicles, namely when the vehicle corresponds to each learning function and when the vehicle does not correspond to any of the learning functions.

As a result, the entering and leaving times were assumed for the ten vehicles, namely cases that each learning function could be applicable and the learning functions could not be applicable. The results are shown in Table 1. The data was selected randomly. And, the values of m_1, m_2, and m_3 which are common to all vehicles, were set to 10. The entering time was the shortest in the case of 'without learning function.' The time required to travel to the final entering location in Figure 4 is longer in the case of 'learning function.' In addition, the cases of 'learning function' achieve good results with regard to leaving time. However, learning functions (2) and (3) had better effects than learning function (1). The reason is that the learning functions (2) and (3) are closer to the final entering location. Each data is shown in Table 2, and the final entering positions are also indicated.

9. Conclusion

Customers complete the parking check-in process by getting off at the entrance of the parking lot in a valet parking. This means that the customer does not have to wait for the vehicle to be parked, or to know the location where it was parked. In other words, customers do not need to worry if it takes a long time to park in the pallet. The time of the vehicle in the parking lot is proportional to the cost (including personnel costs) to the parking lot managers. The managers are more concerned about the cost. What customers are most concerned about is the time it takes to leave the parking lot and the parking fee. The reduction of leaving time is particularly considered in this study.

The top two floors (m_2 and $m_2 - 1$) and the locations at coordinates (1, i, 1) (i = 1, 2, 3, . . ., m_2) on the entrance side were designated as the areas where parking was not permitted in previous research. However, it is possible to further reduce the time it takes for the vehicle to leave the parking lot when a space where it cannot be parked is provided on the exit side.

Three types of learning functions are discussed to reduce each leaving time in this study. The first learning function (1) had a reduced effect compared to the other learning functions (2) and (3) due to the structure of the used parking lot model. The reason for this is that only learning functions (2) and (3) can park the cell pallet near the goal. The leaving process was performed using three different learning functions in this study, but it may be possible to further reduce the overall leaving time by combining these functions into one.

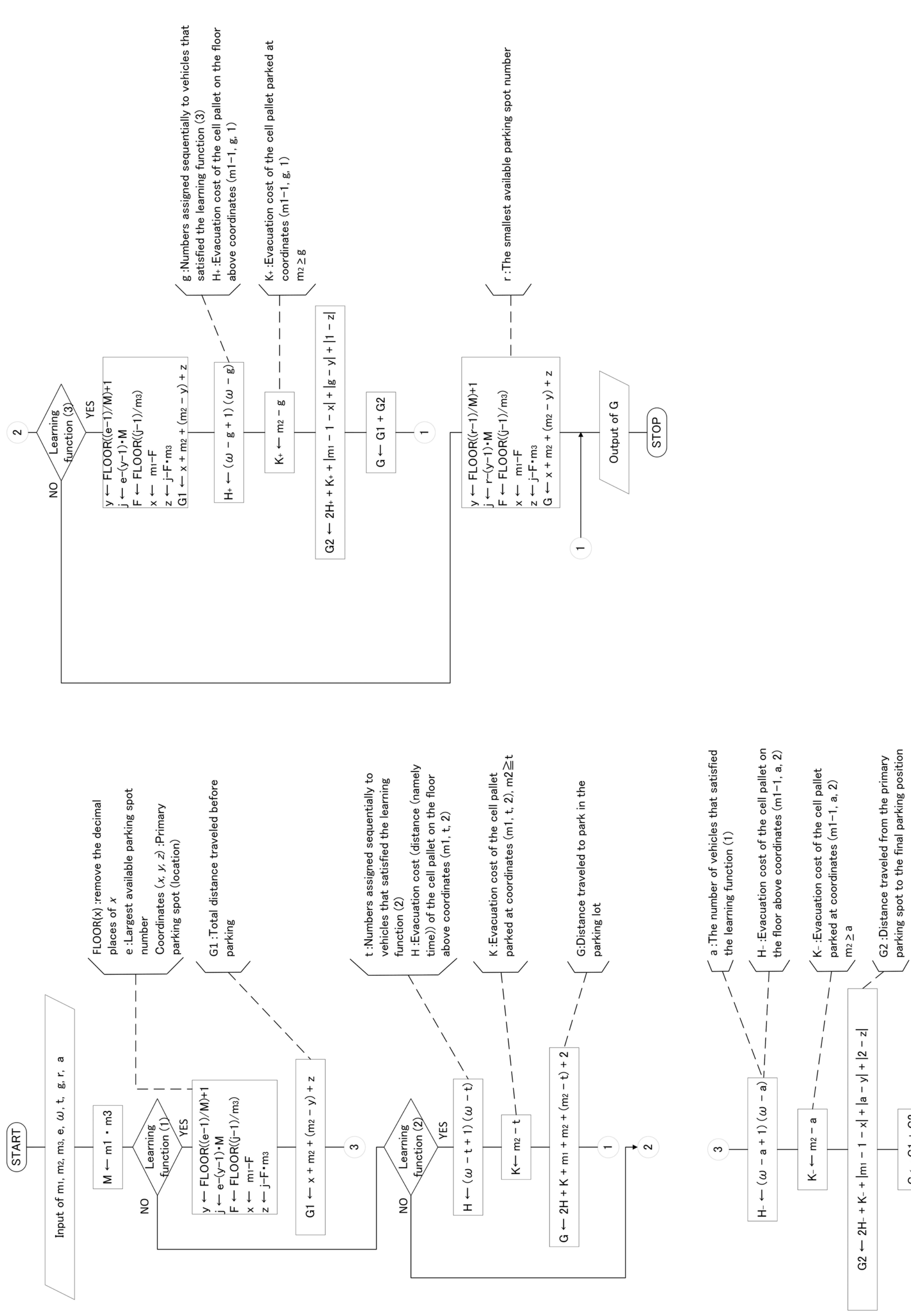

Figure 2: Flowchart for calculating the time taken for each vehicle to park in the derived lot

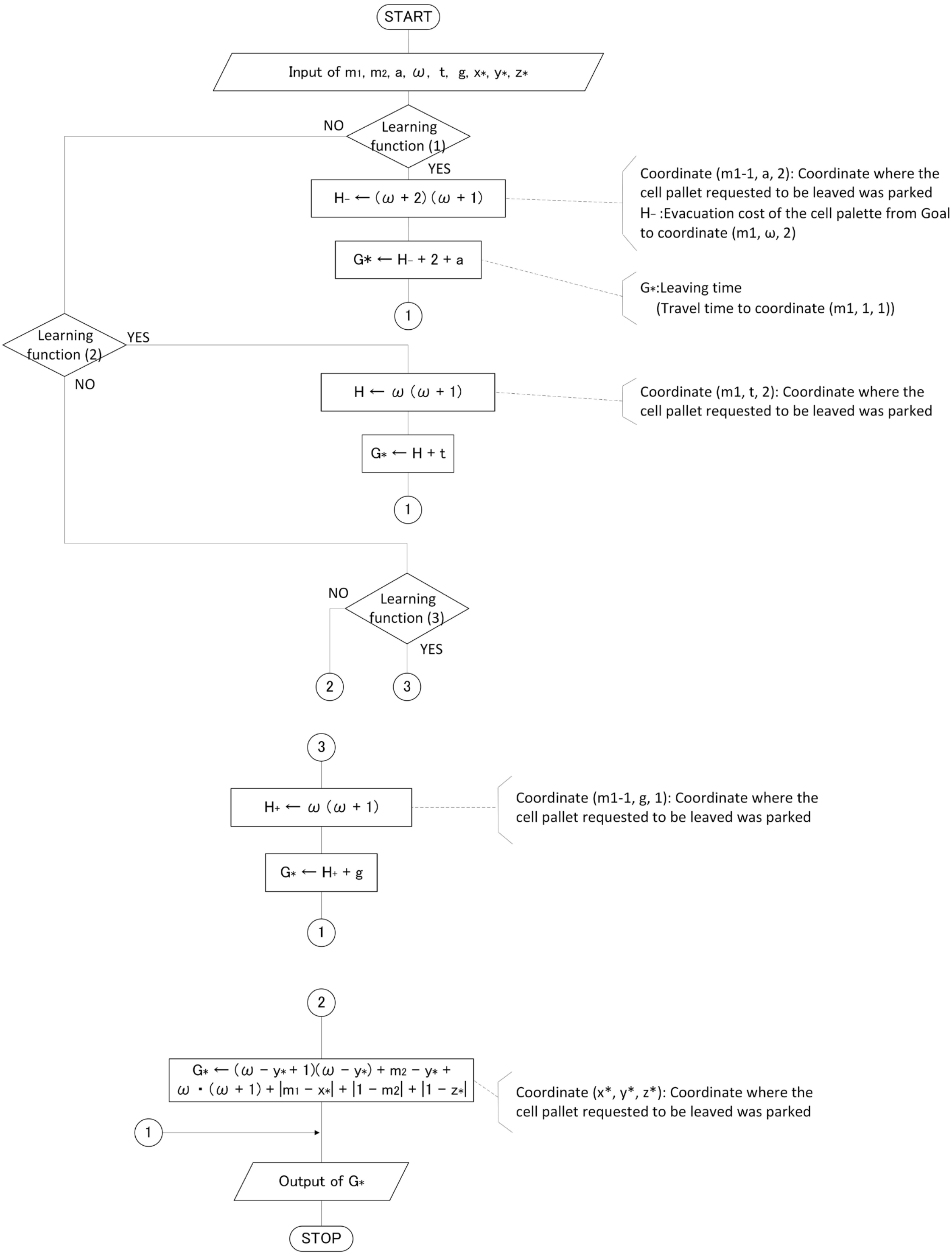

Figure 3: Flowchart for calculating the leaving time per a vehicle

However, the increased evacuation costs, etc. are a problem.

In the leaving algorithm 'without learning function,' the cell pallet parked at coordinate (x*, y*, z*) was moved to coordinates (x*, m_2, z*) and then to coordinates (m_1, 1, 1). However, it was found that the leaving time could be improved by changing the coordinates (x*, m_2, z*) to (x*, ω + 2, z*). But, the leaving time did not still reach that of the 'with learning function' system. For example, the result in Table 1 for data No. 7 was 61, and the result when changed to the coordinates (x*, ω + 2, z*) was 53. On the other hand, the results of the 'learning function' were 35, 23, and 24. And the ones for 'learning function' were more efficient in all cases. The results in Table 1 indicate the following:

- In terms of time required for entering the parking lot, the required time is shorter for the 'without learning function'

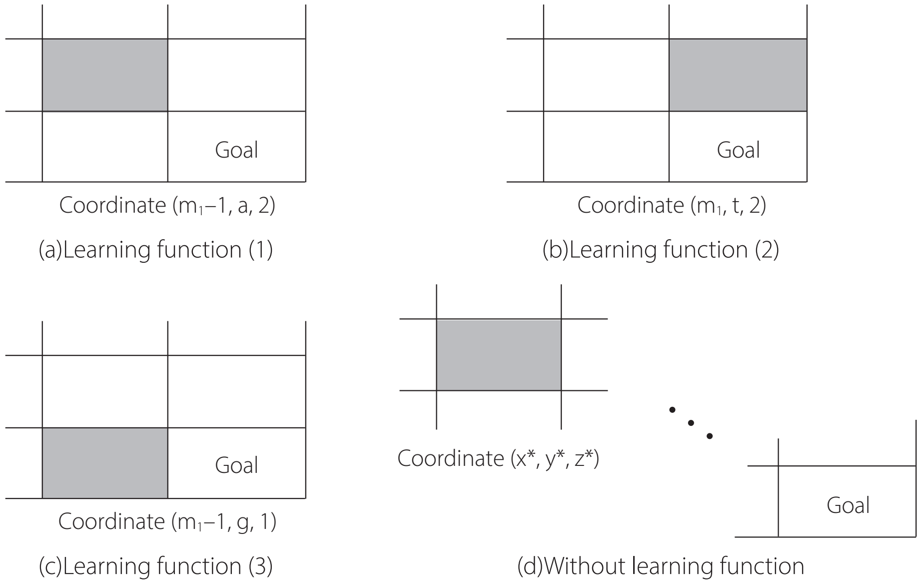

Figure 4: Final entering positions of the cell palette for each learning function

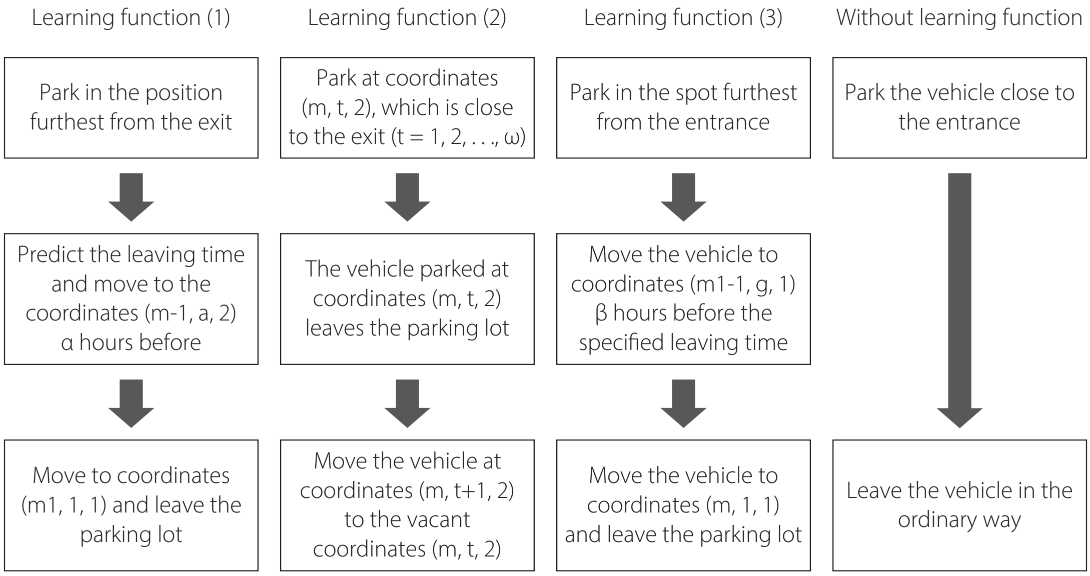

Figure 5: The movement of entering and leaving when the corresponding learning function is present

than the one for 'learning function.' The results for 'without learning function' were approximately 35-50 % of those for 'with learning function.'

- In terms of time required for leaving the parking lot, the required time is shorter for the 'with learning function' than the one for 'without learning function.' The results for 'learning function' were approximately 44-63 % of those for 'without learning function.'
- The leaving time for 'learning function (2)' and the one for 'learning function (3)' were almost the same. Although the efficiency of 'learning function (1)' was reduced than the ones for 'learning function (2)' and 'learning function (3),' the leaving time was approximately 1.45 times longer.

Uniform random numbers were used as input data for simplicity in this study. Normal random numbers should be originally used to take into account realistic situations and to consider the required prediction accuracy.

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References

Atheef, M. S., Sundar, K. S., Kumar, P. P. P., and Karthika, J. (2024). AI-based smart vehicle parking system. *SAE Technical Paper*, 2024-01-5242.

Funase, S., Shimauchi, T., Nambo, H., and Kimura, H. (2022a). A proposal of automated valet parking system using automatic pallet. *Studies in Science and Technology*, Vol. 11, No. 2,

Table 1: Entering and leaving times

Data No.	Learning function (1)		Learning function (2)		Learning function (3)		Without Learning function	
	Entering	Leaving	Entering	Leaving	Entering	Leaving	Entering	Leaving
1	45	9	38	4	48	3	33	27
2	55	10	40	3	60	4	33	25
3	55	9	40	3	58	3	23	25
4	61	15	44	7	60	8	29	29
5	67	23	52	13	70	13	25	38
6	57	24	42	14	70	13	27	41
7	55	35	40	23	58	24	29	61
8	95	45	62	32	70	33	27	64
9	113	76	98	58	118	58	23	84
10	167	93	74	76	98	76	18	140
Average	77	33.9	53	23.3	71	23.5	26.7	53.4

Table 2: Data used in the experiment

Data No.	e	ω	t	g	r	a	x*	y*	z*
1	25	1	2	1	26	1	10	1	8
2	50	1	1	2	15	2	9	1	5
3	70	1	1	1	71	1	7	1	3
4	110	2	1	2	11	1	9	1	3
5	230	3	1	1	231	1	3	2	1
6	300	3	2	1	301	2	4	2	5
7	380	4	3	4	202	3	5	1	7
8	500	5	2	3	211	1	2	3	5
9	700	7	2	2	701	2	5	6	9
10	750	8	4	4	751	1	5	2	5

pp. 147-150.

Funase, S., Shimauchi, T., Kimura, H., and Nambo, H. (2022b). A proposal of parking location determination method to realize high time-efficient exit operations in automated valet parking using automatic pallets. *International Journal of Engineering and Technical Research*, Vol. 12, No. 2, pp. 1-8.

Funase, S., Shimauchi, T., Kimura, H., and Nambo , H. (2022c). Proposal of a multi-story car park with cell pallets to maximize space utilization efficiency in confined area. *International Journal of Engineering and Technical Research*, Vol. 12, No. 1, pp. 1-5.

Funase, S., Moriuchi, T., Kimura, H., and Nambo, H. (2023a). Simulation of auto valet parking using automatic pallets. *Studies in Science and Technology*, Vol. 12, No. 1, pp. 53-66.

Funase, S., Kimura, H., and Nambo, H. (2023b). How to move automatic pallets to improve the time efficiency of exiting in auto valet parking. *Sensors and Materials*, Vol. 35, No. 7, pp. 2229-2239.

Funase, S., Kimura, H., Okada, K., and Hirobayashi, S. (2024). Proposal of an auto valet parking to maximize space utilization efficiency in three-dimensional area. *International Journal of Engineering and Technical Research*, Vol. 14, No. 1, pp. 23-32.

Khalid, M., Wang, K., Aslam, N., Cao, Y., Ahmad, N., and Khan, M. K. (2021). From smart parking towards autonomous valet parking: A survey, challenges and future Works. *Journal of Network and Computer Applications*, Vol. 175, 102935.

Kitagawa Corporation (2021). *Shingata jisoushiki rittai chusyajyou supa longu supan taipu* [A new drive-in multi-story parking: Super long-span system] (Retrieved March 20, 2022 from http://kobayashi.hub.hit-u.ac.jp/topics/rand.html). (in Japanese)

NEC (2022). Smartcity (Retrieved August 20, 2022 from https://www.nec-solutioninnovators.co.jp). (in Japanese)

Okada, K., Funase, S., Kimura, H., and Hirobayashi, S. (2024a). Efficiency comparison of the automated valet parking lot using simulations. *Studies in Science and Technology*, Vol. 13, No. 2, pp. 171-180.

Okada, K., Kimura, H., Oyabu, T., Hirobayashi, S., and Nambo, H. (2024b). Three considerations for speeding up automated valet parking. *Studies in Science and Technology*, Vol. 13, No. 2, pp. 203-210.

Takacs, A. and Haidegger, T. (2024). A method for mapping V2X communication requirements to highly automated and autonomous vehicle functions. *Future Internet*, Vol. 16, No. 4, 108.

Yamamoto, K., Teng, R., and Sato, K. (2023). Simulation evaluation of vehicle movement model using spatio-temporal grid reservation for automated valet parking. *IEEE Open Journal of Intelligent Transportation Systems*, Vo. 4, pp. 261-266.

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