Note

Three considerations for speeding up automated valet parking

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Abstract

It is becoming difficult to secure parking lots especially in an urban area. Multi-story parking lots are being constructed to efficiently utilize limited parking spaces. However, the number of parking spaces per unit area has been reduced in the consideration of traffic accidents within the parking lot and the ease of movement. In addition, incidents such as theft in parking lots have become a problem. Recently, there are some valet parking systems that increase the number of parking spaces per unit area, making it easier to move around in the parking lot, and preventing incidents such as theft. The parking lot staff take care of entering and exiting the parking lot in this parking method. There were problems with labor costs and securing highly skilled personnel in this parking system. An automatic valet parking system has been devised but it has not yet been put into practical use. Several papers have proposed the basic systems, the efficient algorithms for parking a vehicle (parking), and algorithms for taking vehicles out of a parking lot (leaving). Three studies to speed up an automatic valet parking are conducted in this paper.

Key words

automated valet parking, multi-story parking lot, algorithm for leaving the parking lot, parked time, leaving time

1. Introduction

A parking lot (Wikipedia, 2022) is a space for parking vehicles (cars), and can be broadly divided into a flat parking lot and a multi-story parking lot (Asai, 2001). The flat type lots locate on the ground and are the most common type. The ground space is divided according to the size of the car to be parked in this type. There are two types of multi-story (level) parking, namely self-propelled and mechanical. A multi-story parking lot is better when considering parking efficiency relative to land size (Yahoo Japan, 2022). The design of a multi-story parking lot changes depending on the number of people who park permanently or temporary cars, and the purpose of the parking lot. It is also designed with consideration to harmony with the location, safety, and convenience. One type of multi-story parking lot is the ‘mechanical type’ (Kagoshima, 2018; Driver, 2009; Takada, 2015). In this type, cars are stacked one above the other in the first and second tiers. There are various types, including types that move up and down only in the vertical direction (two-tier/multi-tier parking lot) and types that move up and down and left and right (tower parking lot: vertical circulation system which is called an elevator system). In any case, the user has to get out of the car and put it away, which is time-consuming for the user. In addition, this system requires special equipment which increases the cost. However, there are many parking spaces per unit space, which has the advantage of being able to more efficiently secure the number of parking spaces. In addition to the ‘mechanical type’, there is also the ‘self-propelled type.’ This method allows the driver to park while driving, and the drivers can drive and park by themselves (Watahan Solution, 2022). This type requires less manpower and it is easier for users to park compared to the ‘mechanical type.’ Its efficiency in terms of the number of parking spaces is inferior to that of the ‘mechanical type’ since the number of parking spaces per unit area is smaller than that of the ‘mechanical type.’ Multi-story parking systems have been studied as cars become self-driving, and automatic valet parking has also been proposed (Kitagawa Corporation, 2021). This system can allow cars to automatically enter and exit the parking lot. It has not yet been put into practical use. The main reason for this is the attempt to realize self-driving cars using mobile phones. This is because the control methods of customers’ cars vary widely, and one-size-fits-all control is not possible. Each car has a wide variety, and differs in performance and appearance.

Parking issues are an important challenge in the smart city concept (NEC, 2022), which is a national policy. As the scale of multi-story parking lots increases, some problems such as accidents (traffic accidents, theft accidents, etc.), searching for parking spaces, narrow enter/exit area from the car, and difficulty for beginners and elderly people to use the parking structures have become problems. The authors of this paper proposed an automatic valet parking using a unique automatic pallet to solve these problems (Funase et al., 2022a). The authors also proposed a time-efficient parking location determination method for exiting from the parking lots (Funase et al., 2022b). Furthermore, the authors proposed an automatic pallet movement method that improved the efficiency of leaving time from the parking position (Funase et al., 2022c). In the study, it was examined if the time efficiency for leaving from a lot can be improved by simulation (Funase et al., 2023b). The target of this study was to make maximum use of three-dimensional space in a multi-story parking lot. A part of this study was published in a previous report (Funase et al., 2022c). Another study also demonstrated the basic parking and exit algorithms for multi-story parking lots (Funase et al., 2024). Improvements to this paper were then proposed (Okada et al., 2024). The multi-story parking lot summarized in these studies was a type of mechanical multi-story parking lot equipped with one elevator for entering and one elevator for exiting (Funase et al., 2022a; 2022c; 2023a; 2023b; 2024; Okada et al., 2024).

This paper considers the following three proposals for speeding up automatic valet parking. (1) The cell pallet lastly entered is moved to the space vacated by taking out the car in Okada et al.'s (2024) proposal. In this proposal, the cell pallet is moved to a space with a lower parking position number than that of Funase et al.'s (2024) proposal. However, the cell pallet closest to the exit is not selected. The selected cell pallet may be close to the exit or far from it. Choosing a pallet close to the exit is more efficient in exit time. (2) If a car is parked at parking position No. 2 or the higher parking position number, or if a car is parked at parking position No. $m_3 + 1$ or the higher parking position number, the car can easily exit the parking lot. Therefore, it is better to adopt a method different from the exit algorithms for other parking position numbers. (3) The parking position numbers in Figure 3 of Okada et al.'s (2024) paper are not changed, and it is considered how to change the order of parking positions when entering the parking lot to speed up the automatic valet parking. It is considered specifically how to arrange the parking positions when entering the parking lot to minimize the total travel distance (cost) required for exiting all parked cars.

2. Consideration of proposal (1)

First, an improvement plan for the reference (Okada et al., 2024) is proposed. It is an improved version of the paper (Funase et al., 2024). In the paper, the cell pallet where the last car arrived is moved into the space vacated by taking a car out of the parking lot. However, the pallet is not closer to the exit than before it was moved. The only thing is that the parking position number where a user parks the car is smaller, and may move closer to the exit or move away from it. Therefore, the authors investigated which of the following conditions is valid.

- Move the cell pallet that a car arrived at lastly to the space vacated by taking a car out of the parking lot.
- Leave the space vacated by taking a car out. At this time, the distance (travel cost) in the following two cases is compared and the smaller one is selected.
- The distance from the cell pallet position where the last car entered the lot to the coordinates (m_1, 1, 1) every time a car leaves the parking lot.
- The distance from the current position of the cell pallet to the coordinates (m_1, 1, 1) when the cell pallet that a car lastly arrived is moved to the space vacated by taking a car out of the parking lot.

Here, m_1 is the number of parking spaces in the horizontal direction of the multi-story parking lot. The flowchart of this process is shown in Figure 1. Note that Figure 1 is an improved version of Figure 8 in the reference of Okada et al. (2024). Table 1 shows the execution results of the program shown in the flowchart in Figure 1. The results of Okada et al. (2024) are shown in Table 2. The result was the opposite of what was expected.

In proposal (1), the leaving cost is compared between the case of moving the last entering cell pallet to the vacated space and the case for not moving it, and the smaller one is selected. In this case, if only leaving is considered, the time will be shorter. However, the parking efficiency decreases in a high-rise parking lot, when the value of the top floor (ω) is not small. The formula for calculating the leaving time also includes a quadratic formula for ω. If ω becomes even slightly smaller, the cost will drop significantly. The cars that have recently entered the parking lot are parked on the upper floors of the parking lot, so they are often less expensive than cars leaving the parking lot, so they are not often moved. As a result, ω remains at a large value and the overall leaving efficiency decreases. And, in the reference of Okada et al. (2024), when cars leave the lot, the last car that entered the lot will always move, so the top floor of the lot that cars are parked (it means the number of floors) will go down. This difference has a big impact on the results. In addition, when a pallet is moving, it is necessary to consider 'the number of times it has been moved' and 'the number of times it has not been moved'. When the number of entering cars is small, 'the number of times it has been moved' increases. When the number of entering cars is large, 'the number of times it has been not moved' increases. From the above results, it is better to move a cell pallet that a car entered to the vacant space after the car left the parking space in terms of the time cost of leaving.

3. Consideration of proposal (2)

According to the results investigated so far, the most efficient retrieval algorithm is the one in the reference of Okada et al. (2024). However, it is considered that it would be more efficient to use a unique algorithm for a car to leave from a cell pallet parked at certain parking location numbers near the exit. The following proposals can be considered specifically.

3.1 Leaving a car from no. 1 of parking position and upper floor

If the cell pallet of the car scheduled to leave the parking lot is parked at parking position No. 1, the vehicle is just allowed to leave the parking lot (see Figure 2). If the cell pallet

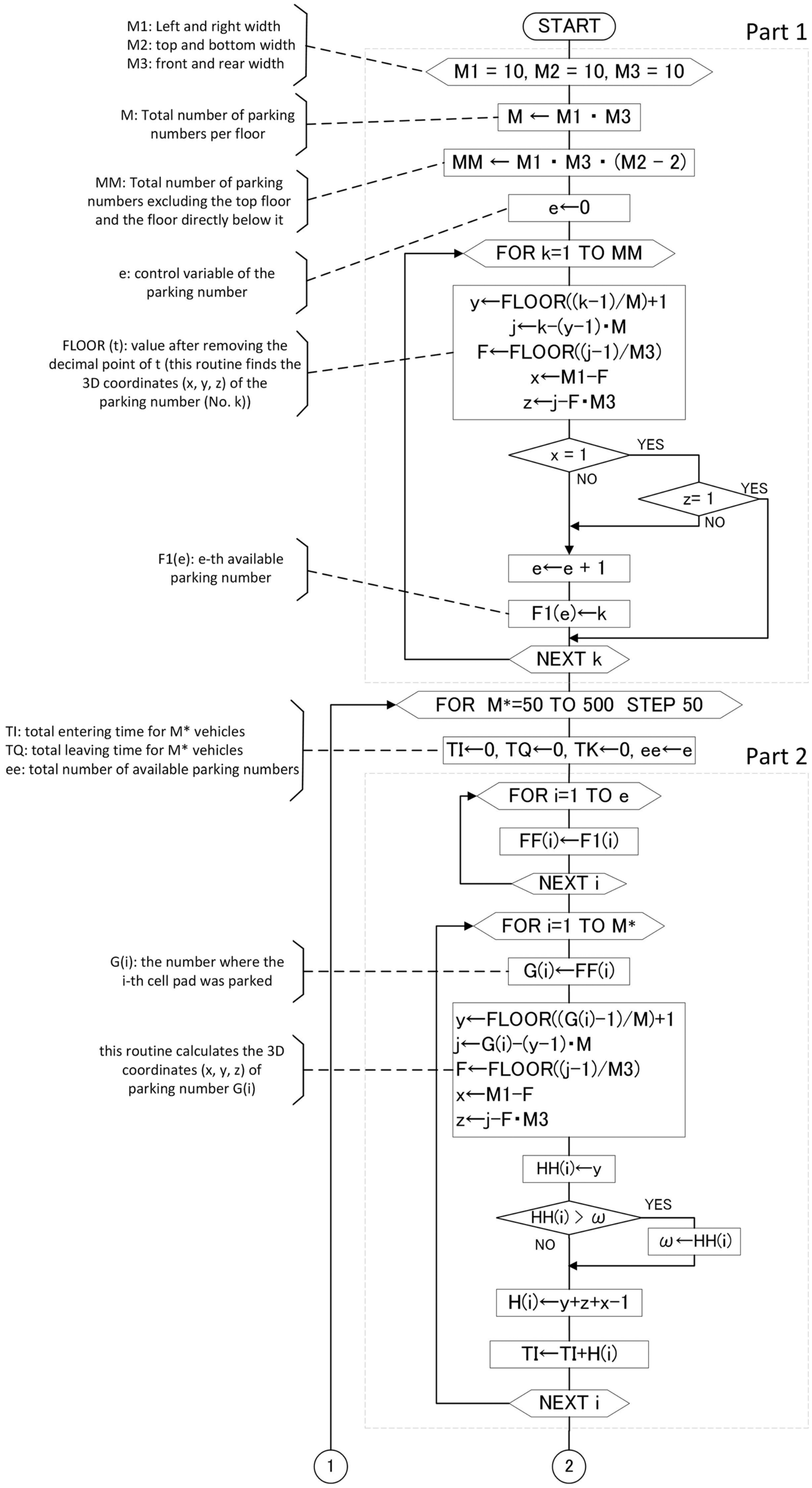

Figure 1: Flowchart to derive each value of proposal (1)-1

Note: Total arriving (entering) time and total leaving (exiting) time (cost), total operation time that reduces the leaving time, number of times the cell pallet was moved to a space vacated by leaving, number of times the cell pallet did not move.

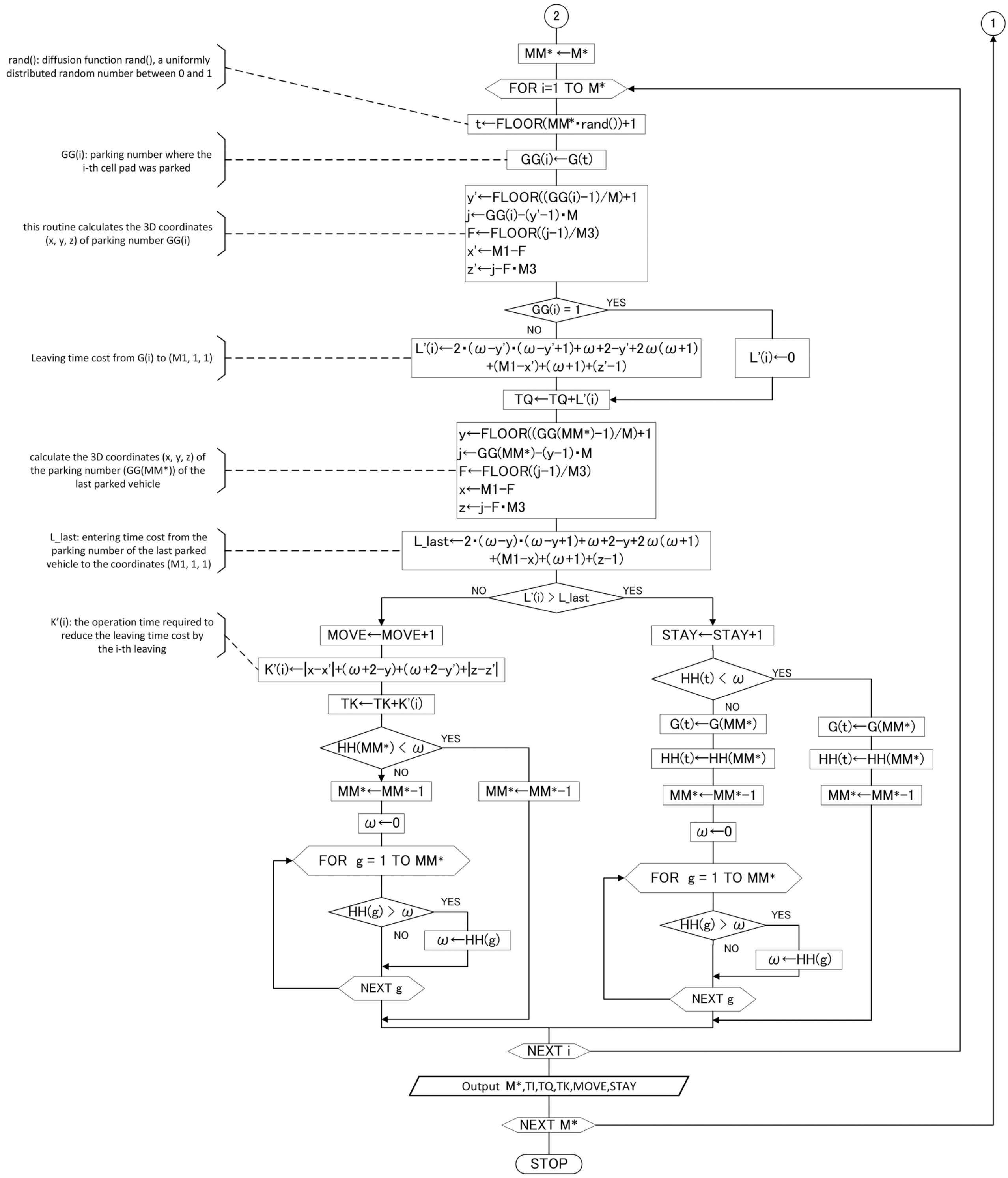

Figure 1: Flowchart to derive each value of proposal (1)-2

scheduled to leave is parked on the upper floor of parking position No. 1, the cell pallet parked on parking position No. 1 and the upper floor thereof is temporarily moved. At that time, the cell pallet scheduled to leave is moved to parking position No. 1 and leaves. After that, the cell pallet that was moved returns to the first floor. In the reference of Okada et al. (2024), the cost of the quadratic expression of ω affects the movement of the target cell pallet scheduled to leave to parking position No. 1. On the other hand, ω is a linear expression in the proposed method and the cost is low.

3.2 Leaving a car from parking position no. 2 and upper floor

The cell pallets parked on the lower floor move to the nearest empty parking space on the upper floor to vacate the

Table 1: Total entering time (cost) and total leaving time cost in proposal (1)

Number of entering vehicles	Total entering time cost	Total leaving time cost	Total operation time to reduce the leaving time cost	Number of times a car (pallet) has moved	Number of times a car did not move
50	2200	596	289	30	20
100	3035	2544	1067	76	24
150	5280	3791	781	54	96
200	6181	9032	1083	65	135
250	8466	10395	1610	102	148
300	9438	19973	1851	102	198
350	11758	22250	2444	135	215
400	12806	37416	2857	140	260
450	15156	40977	3076	149	301
500	16285	62865	3897	173	327

Note: Total operation time that reduces leaving time (cost), number of times the pallet was moved to a space vacated by leaving and number of times not moved.

Table 2: Results of literature

Number of entering vehicles	Total entering time cost	Total leaving time cost	Total operation time to reduce the leaving time cost
50	2200	591	502
100	3035	1380	1153
150	5280	2943	1858
200	6181	4397	2611
250	8466	6509	3437
300	9438	8857	4180
350	11758	12546	5136
400	12806	15887	6154
450	15156	21027	7112
500	16285	26079	8196

Source: Okada (2024).

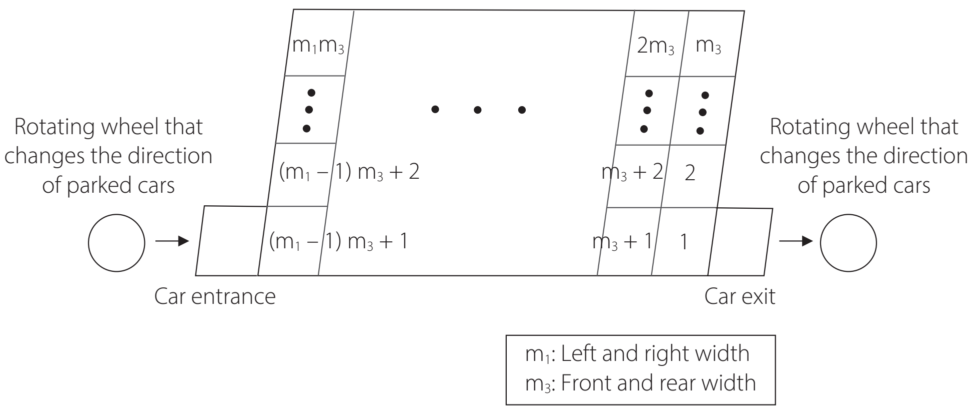

Figure 2: Parking position number on the first floor

Source: Okada et al. (2024).

parking position No. 1. If the cell pallet scheduled to leave is at parking position No. 2, it is moved to parking position No. 1 (see Figure 2). If the cell pallet scheduled to leave is parked on the upper floor of parking position No. 2, the cell pallet parked at parking position No. 2 (and the upper floor) is temporarily moved. The target cell pallet scheduled to leave is moved to parking position No. 1 via parking position No. 2 and leaves. After that, the cell pallet that was moved to the first floor is moved. In the reference of Okada et al. (2024), it takes a quadratic equation cost of ω to move the target cell pallet scheduled to leave to parking position No. 1. In contrast, the proposed method requires only the cost of the linear expression of ω.

3.3 Leaving a car from parking location no. (m_3 + 1) and upper floor

The idea is the same as Section 3.2. The cell pallet parked on the lower floor is sequentially moved to parking position No. 1 or the nearest empty position on the upper floor. This move will free up parking position No.1. If a cell pallet scheduled to leave is parked at parking position No. (m_3 + 1), it is moved to parking position No.1 (see Figure 2). If the cell pallet scheduled to leave is parked on the upper floor of parking position No. (m_3 + 1), the cell pallets parked at parking position No. (m_3 + 1) and the upper floor thereof are temporarily evacuated. At that time, the cell pallet that is scheduled to leave is selected and it is moved to the parking position No. 1 via parking position No. (m_3 + 1) and it leaves. After that, the cell pallet that was moved (evacuated) is returned to the first floor to fill the gap. The cost of the quadratic equation of ω is required to move the target cell pallet scheduled to leave to parking position No. 1 in the reference of Okada et al. (2024). In contrast, the proposed method requires only the cost of the linear expression of ω.

4. Consideration of proposal (3)

The leaving time cost (L′ (i)) is expressed by the following formula. It means the moving time cost from the parking position number where the i-th cell pallet was parked (coordinates (x′, y′, z′)) to coordinates (m_1, 1, 1),

$$L'(i) = 2(\omega - y')(\omega - y' + 1) + \omega + 2 - y' + 2\omega(\omega + 1) + (m_1 - x') + (\omega + 1) + (z' - 1) \quad (1)$$

Here, ω is the top floor where the cell pallet is parked. As the coordinate (x′, y′, z′) is determined by random numbers, the values of x′, y′ and z′ are unknown. m_1 is a fixed value since it is given. ω is a value determined by the entering algorithm. ω was the smallest when entering algorithm ② was used in the reference of Okada et al. (2024). The entering algorithm is improved in this paper. The flowchart is shown in Figure 3.

The execution results of the program coded with the flowchart in Figure 3 is shown in Table 3. The entering method for Okada et al. (2024) is changed in proposal (3). Vehicles were parked in order of parking position number when parking. However, in proposal (3), parking was performed from the parking position number closest to the entrance. Namely, the order of parking positions is determined in descending order of w (= x + y) for two-dimensional coordinates (x, y). In other words, the parking is performed from a parking position close to the entrance in order to reduce the cost of entering.

Comparing the results of proposal (3) and Okada et al. (2024) in Table 2, it can be seen that the leaving cost can be reduced slightly overall. Some reductions in entering costs are observed when the number of vehicles in the parking lot is 50, 150, 250, 350, and 450. This is because the parking position of vehicles parked on the top floor is closer to the exit. This result is different from Okada et al.'s (2024) result. In the case of 100 parking vehicles and 200 parking vehicles, the reason that the entering cost cannot be reduced is because the number of vehicles that can be parked on the top floor is small. The number of vehicles parked on the top floor is only one in the parking lot with the capacity of 100 vehicles, and the entering cost is the same as Okada et al. (2024). The number of vehicles parked on the top floor is two when there are 200 parking spaces. The entering cost is almost the same as the result of Okada et al. (2024).

5. Conclusion

Parking lot users at the following facilities feel stressed: shopping malls, large complex buildings, theme parks and airports. There are two main causes of the stress: 'user cannot find a parking space' or 'parking place is far'. In addition, the limited parking spaces cannot be used efficiently in urban areas. Parking intervals are not even minimized. Many countries around the world, including Japan, Europe, the U.S.A., and China, are investigating the practical application of automatic valet parking systems using autonomous driving technology to solve these problems. It is necessary to establish internationally unified standards for system operations, processes, and interface specifications between vehicles and parking lots under these circumstances. Various results have been obtained from vehicle research and demonstration experiments in Japan. The automatic valet parking systems with common functions and methods must be widely disseminated based on those results around the world. An international standard for 'automated valet parking' jointly developed by Japan and Germany was published in 2023. It will contribute to the effective use of parking lot spaces and the reduction of accidents in parking lots when this technology becomes widespread. This eliminates the need for users to perform operations in the parking lot, and eliminates the need to search for a parking spot and wait for an available parking space. This standard is expected to improve user convenience and

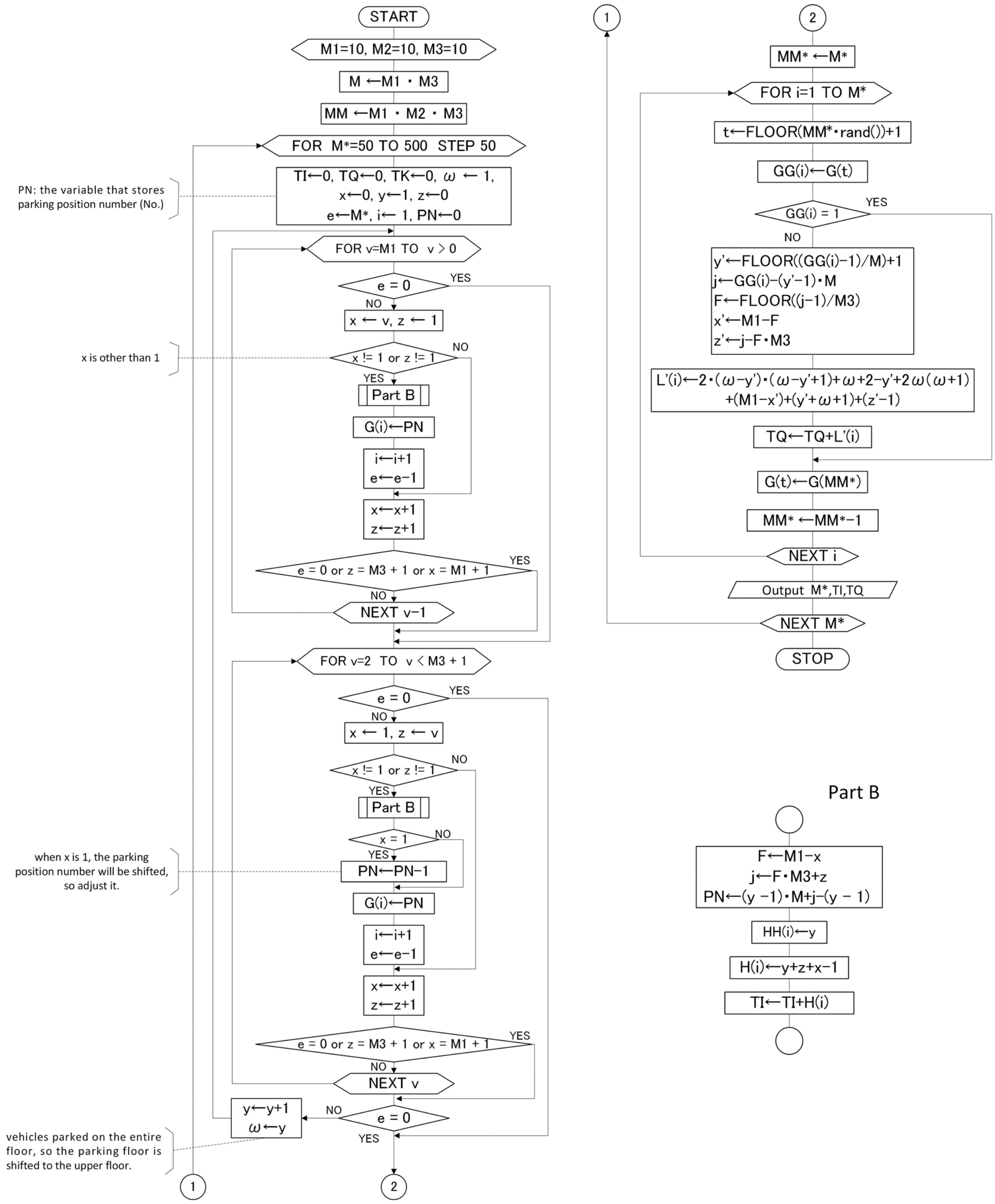

Figure 3: Flowchart for calculating the total car entering time cost, the total leaving time cost, and the total work time to reduce the leaving time cost in proposal (3)

reduce carbon dioxide emissions. However, the automatic valet parking system has not yet been put into practical use. The multi-story parking lot targeted in this study has only parking spaces and it does not consider the space for walkways or slopes. The car is moved through the parking spaces to the desired parking space. In addition, instead of having someone drive the customer's car, the car is transported on a special electric pallet called the cell pallet, which is the size of a normal parking space for a car. The multi-story parking lot is made up of a skeleton of poles, similar to the jungle gym in a park. The cell palette moves left and right, up and down, and back and forth in the jungle gym. In other words, the customer's car is parked on the cell pallet. In this paper, an efficient automatic valet parking system that is practical and makes maximum use of three-dimensional space is investigated. In addition, three points regarding speeding up the parking system are considered.

Table 3: Each value when changing the number of entering vehicles in the parking lot, namely the total entering time cost, the total leaving time cost and the total work time to reduce the leaving time cost in proposal (3)

Number of entering vehicles	Total entering time cost	Total leaving time cost	Total operation time to reduce the leaving time cost
50	1410	524	499
100	3035	1288	1200
150	4534	2739	1975
200	6170	4261	2572
250	7774	6438	3449
300	9417	8797	4295
350	11132	12526	5124
400	12753	15826	6177
450	14610	20966	7251
500	16200	25352	8136

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