Efficiency comparison of an automated valet parking lot using simulations

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Abstract

In this research, in order to find a high efficiency automated valet parking lot, a multi-story car parking proposed by the authors, possible algorisms of entering and exiting are proposed. And, by combining those algorisms, efficiency comparisons of the automated valet parking lot were simulated. The algorisms were as follows: (1) The entering location number is decided with uniform random numbers. This is the most realistic entering method. (2) The target location of entering is decided in order of the smallest number available. Therefore, if a location which is close to the exit is available, even a car entering later can park there. (3) Entering cars will be parked in order of the smallest number of parking location. If locations are full, "garbage collection" will be performed to fill up the empty parking locations in order of the smallest parking location number (starting from close to the exit), then creating an empty space in a far parking location from the exit. Next, exiting algorisms which were used are as follows: (1) Move the car that was requested to exit to the exit. (2) Move the car that was requested to exit to the exit, then the latest entering car is moved to the parking location which is available. (3) Move the car that was requested to exit to the exit, then cars parked at the next parking location number are sequentially moved to the available parking spaces. By the results of simulations, which parking method had the highest efficiency as an automated valet parking lot was clearly shown, and useful features were demonstrated.

Key words
multi-story car parking, cell pallet, automated valet parking, entering method, exiting method

1. Introduction

A parking lot (Wikipedia, 2022) is a place for parking a car and can be roughly divided into a flat parking lot and a multi-story parking lot (Asai, 2001). Additionally, a multi-story car parking lot is self-propelled and mechanical. When considering an efficient parking lot, it is a mechanical multi-story car parking lot (Driver, 2009; Takada, 2015; Kagoshima, 2018). Recently, against the background of the development of self-driving cars, research has been conducted on the ideal form of multi-story car park for these vehicles (Kitagawa Corporation, 2021). The ideal form of parking lot is one that is friendly to both the environment and users. These are parking lots that automatically enter and exit by self-drive. But that way has not yet been put to practical use. The main reason for this is the lack of accuracy in automated driving and the lack of support for a wide variety of vehicles. As the scale of multi-story car parking grows, it is pointed out that the systems have problems such as accidents, theft, searching for parking spaces, boarding/deboarding at narrow designated places, and difficulty in using for beginners and elderly people. To solve these issues, this research proposed an automated valet parking lot using an original automatic pallet (Funase et al., 2022a). The automatic pallet picks up customers' cars and automatically moves them to the required parking locations. This means that customers do not have accidents and do not have to search for parking spaces. In addition, customers get on and off at the exit or entrance of the parking lot, so there is no trouble in narrow boarding areas, making it easy for beginners and the elderly to use. Also, the proposed parking location determination method is to realize high time-efficient exit operations (Funase et al., 2022b). Furthermore, this research proposes how to move automatic pallets to improve the time efficiency of exit operation (Funase et al., 2023a), and clarifies how much the time efficiency of exit operation is improved by simulations (Funase et al., 2023b). The multi-story parking lot covered in the above papers (Funase et al., 2022a; 2022b; 2023a; 2023b) is a self-propelled multi-story parking lot equipped with one elevator for entering and one elevator for exiting. In this research, the multi-story car parking lot that makes the most of the three-dimensional space, proposed in Funase et al. (2022c), will be the focus. This multi-story car parking has the purpose to maximize the number of parking cars. Self-propelled system multi-story parking lots are installed in public facilities, commercial facilities, medical/welfare facilities, amusement facilities and hotels. Since the driver drives and moves the vehicle, in addition to the parking space, additional spaces such as driving lanes, slopes to connect adjacent floors and steps or elevators for drivers are required. It is also required to use special large equipment which are most of the time expensive (Watahan Solutions, 2022). Finally, although it has a higher efficiency in space usage, the number of vehicles that can be accommodated is small. Funase et al. (2022c) proposed a system that combines a multi-story car park that is constructed like a jungle gym by combining poles and an electric pallet that moves both horizontally and vertically with a vehicle on it. And, the car parking possesses the advantages of the existing mechanical and self-propelled types with a large capacity and high parking efficiency per floor area. However, it is not mentioned in the paper (Funase et al., 2022c) how to enter and exit. The paper (Funase et al., 2024) shows a method for entering and exiting a parking lot in order to propose automated valet parking that makes maximum use of the three-dimensional space. However, verification of efficiency is not sufficient. In the experiment, a method using the proposed algorithm and a method using random numbers were compared to derive the total entering time and total exiting time when m cars were sequentially entered and then sequentially exited.

Therefore, in this current paper, in order to find the high efficiency automated valet parking lot, a multi-story car parking as proposed in the paper (Funase et al., 2022c), the authors propose possible entering and exiting algorithms, and compare and simulate the efficiency of entering and exiting by combining them. With this, it is possible to find the most efficient automated valet parking available at the moment. For simplicity, sequential control is assumed that does not allow parallel movement of cell pallets.

2. Cell pallet

The cell pallet is an electric pallet (Figure 1) with a floor area equivalent to that of a general parking lot and is used for moving a vehicle to a parking lot and moving from the parking lot to an exit. Its shape is rectangular with four corners trimmed for the gear wheels to be deployed as necessitated. Four electric gear wheels of the pallet are installed on left/right and forward/backward side and one on each corner. The electric gear wheel fits in the groove of the pole of the multi-story car park, which has a structure like a jungle gym, and moves left-right, forward-backward, and up-down while maintaining the stability of the cell pallet.

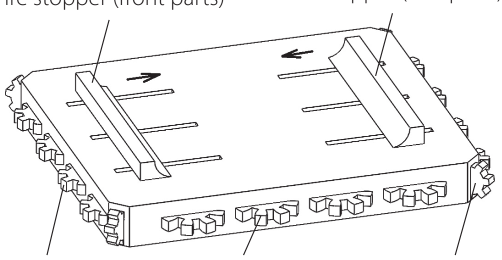

Figure 1: Structure of the cell pallet
Source: Funase et al. (2024).

3. Target multi-story car parking

The target multi-story car parking (Funase et al., 2022c) consists of a pole skeleton (Figure 2) like a jungle gym, in which the cell pallet moves both horizontally and vertically. The entrance of multi-story car parking is at front row 1st floor left end and the exit is at front row 1st right end.

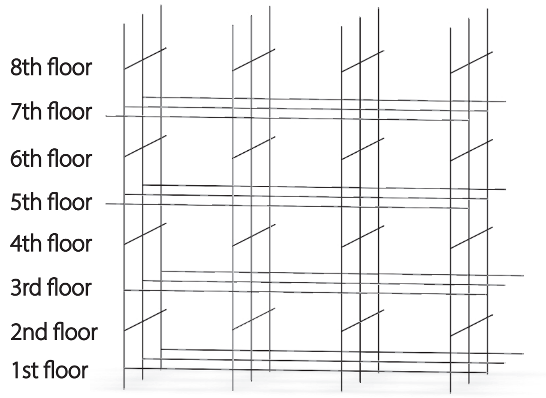

Figure 2: Skelton structure of proposed car parking: 3 × 8 × 2
Source: Funase et al. (2022c).

The reception of entry is at the entrance of parking, and a number card with an ID number is handed to the driver. After that, the car is put on a cell pallet, and moved to coordinate (1, 1, 1). A parking location number is connected with the ID number. The entry algorithm is an algorithm of moving

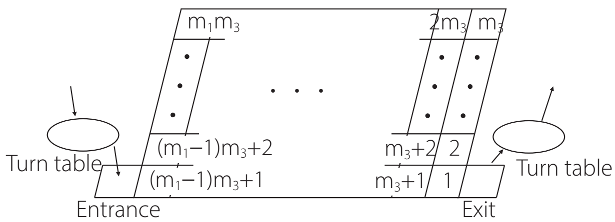

Figure 3: Parking location number on 1st floor
Source: Funase et al. (2024).

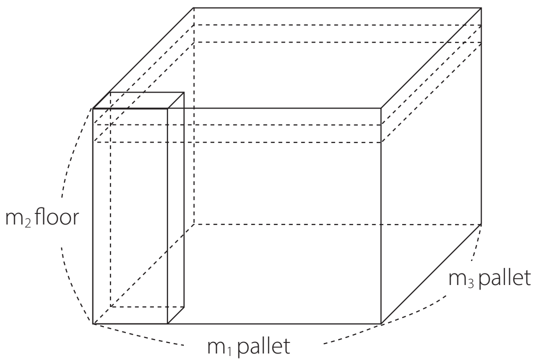

Figure 4: Overall image of target multi-story parking
Note: However, cars do not park on the top floor, next lower floor from top floor and at coordinates (1, i, 1)
Source: Funase et al. (2024).

the cell pallet from (1, 1, 1) to (x, y, z). The parking location number is a serial number that is set to each parking location from the 1st floor to the top floor. And, the parking location number which is directly above the floor from parking location No. j is $m_1m_3 + j$. For example, on the 1st floor, parking locations are allocated as shown in Figure 3. However, in the end of left row, cars do not park at coordinate (1, i, 1) (i = 1, 2, ..., m_2). The m_1 is the number of parking cars per line and m_2 is the number of floors to the top floor. And m_3 is the number of parking cars per row. The top floor (m_2) of the multi-story parking and the floor directly below it ($m_2 - 1$) are used for the movement passage or evacuation of cell pallets. The details are shown in Figure 4.

To exit the car, the customer goes to the exit of the parking lot and presents the ID number card. From the ID number it is possible to find the parking location number of the cell pallet on which the customer's car is placed then the cell pallet is moved to coordinates (m_1, 1, 1). The coordinates (m_1, 1, 1) are adjacent to the exit, and once the exit procedure is completed, the cell pallet stopper is removed and the customer's car can continue to the exit. In other words, this is an algorithm with the coordinates (x′, y′, z′) from the ID number and moves to the coordinates (m_1, 1, 1).

4. Automated valet parking as a comparison target

4.1 Evacuated location for cell pallets

In principle, cell pallets should be evacuated in stacks. If the continuous evacuation is difficult, divided evacuation is also possible. The computer simulation execution time required to generate stacks for evacuation location etc. is not considered because it is instantaneous and within the error range compared to the movement time of the cell pallet.

4.2 Entering algorisms used

4.2.1 Step 1

The entering location number is decided with uniform random numbers. This is the most realistic entering method used this time. However, cell pallets which are parked at coordinates (x, t, z) (t = y + 1, y + 2, ..., $m_2 - 2$) above the coordinates (x, y, z) will be temporarily evacuated to the stack space. The coordinates (x, y, z) are a target entering location. The stack space is $m_2 - 1$ etc. floor.

4.2.2 Step 2

The target location of entering is decided in order of the smallest number which is available. Therefore, if a location which is close to the exit is available, even a car entering later can park there. However, as long as there is no exiting and only entering is continued, stack is not required. The procedure is to park the cell pallets one by one from the lower floor, so the distance moved to park is minimized. It is similar with the entering algorism [4.2.3 Step 3] that is described next, but the top of floor that parks a cell pallet is higher for the algorism [4.2.3 Step 3] than [4.2.2 Step 2].

4.2.3 Step 3

Entering cars will be parked in order of the smallest number of the parking location. If locations are full, "garbage collection" will be performed to fill up the empty parking locations in order of the smallest parking location number (starting from close to the exit), then creating an empty space in the furthest parking location from the exit.

4.3 Exiting algorisms used

4.3.1 Step 1

For the coordinates (x′, y′, z′) corresponding to the parking location of the cell pallet taking the car requested for exit, first of all, the cell pallet that parks at the coordinates (x′, t, z′) (t = y′ + 1, y′ + 2, ..., $m_2 - 2$) is evacuated to $m_2 - 1$ etc. floor. And the cell pallet that parks at the coordinates (x′, y′, z′) is moved to the coordinates (x′, m_2, z′). Then, the evacuated cell pallet returns to its original location. Next, the cell pallet that parks at the coordinates (m_1, t, 1) (t = 1, 2, ..., $m_2 - 2$) is evacuated to m2 – 1 etc. floor. And the cell pallet (coordinates (x′, m_2, z′)) taking the car requested for exit is moved to the coordinates (m1, 1, 1) and to the exit. Then, the evacuated cell pallet returns to its original location.

4.3.2 Step 2

For the coordinates (x′, y′, z′) corresponding to the parking location of the cell pallet taking the car requested for exit, at first, evacuate the cell pallet which parks at the coordinates (x′, t, z′) (t = y′ + 1, y′ + 2, ..., ω) (ω is the top floor in parking cell pallets) to ω + 1 th floor etc.. Then, move the cell pallet at the coordinates (x′, y′, z′) to the coordinates (x′, ω + 2, z′). Next, the latest entering car is moved to the parking location (x′, y′, z′) which is available. Then, the cell pallet that was evacuated returns to before. After that, cell pallets which park at the coordinates (m_1, t, 1) (t = 1, 2, ..., ω) are evacuated to ω + 1 th floor etc. Then, the car which is required for exit on the cell pallet (the coordinates (x′, ω + 2, z′)) is moved to the coordinates (m_1, 1, 1) and the exit. Finally, evacuated cell pallets return to before.

4.3.3 Step 3

For the coordinates (x′, y′, z′) corresponding to the parking location of the cell pallet taking the car requested for exit, evacuate the cell pallet which parks at the coordinates (x′, t, z′) (t = y′ + 1, y′ + 2, ..., ω) to ω + 1 th floor etc.. Then, move the cell pallet at the coordinates (x′, y′, z′) to the coordinates (x′, ω + 2, z′). Next, cell pallets parked at the next parking location number are sequentially moved into the available parking spaces. Then, cell pallets that were evacuated return to before. After that, cell pallets which park at the coordinates (m_1, t, 1) (t = 1, 2, ..., ω) are evacuated to ω+1 th floor etc. Then, the car which is required for exit on the cell pallet (the coordinates (x′, ω + 2, z′)) is moved to the coordinates (m_1, 1, 1) and the exit. Finally, evacuated cell pallets return to before.

However, in all algorisms above, when there is a request for a car at the parking location No.1 to exit, the exiting time cost is 0 (zero) because that car is already parked at coordinates (m_1, 1, 1).

4.4 Target automated valet parking for comparison

[1] Using entering algorism 4.2.1 and exiting algorism 4.3.1 for the automated valet parking: This is the same with the automated valet parking that was used in Experiment 1 of the reference (Funase et al., 2024). In this paper, it was simulated in Experiment 1.

[2] Using entering algorism 4.2.1 and exiting algorism 4.3.2 for the automated valet parking: It was simulated in Experiment 2.

[3] Using entering algorism 4.2.1 and exiting algorism 4.3.3 for the automated valet parking: The efficiency is in Consideration 1.

[4] Using entering algorism 4.2.2 and exiting algorism 4.3.1 for the automated valet parking: It was simulated in Experiment 3.

[5] Using entering algorism 4.2.2 and exiting algorism 4.3.2 for the automated valet parking: This is a revised edition of the automated valet parking that was used in Experiment 2 of the reference (Funase et al., 2024). In this paper, it was simulated in Experiment 4.

[6] Using entering algorism 4.2.2 and exiting algorism 4.3.3 for the automated valet parking: The efficiency is in Consideration 1.

[7] Using entering algorism 4.2.3 and exiting algorism 4.3.1 for the automated valet parking: The efficiency is in Consideration 2.

[8] Using entering algorism 4.2.3 and exiting algorism 4.3.2 for the automated valet parking: The efficiency is in Consideration 2.

[9] Using entering algorism 4.2.3 and exiting algorism 4.3.3 for the automated valet parking: The efficiency is in Consideration 1 and 2.

Here, the revision edition of the automated valet parking that was used in Experiment 2 of the reference (Funase et al., 2024) have improvement points as below.

(a) The parking No.k that was written in Operation 3 of exiting algorism 2 in Funase et al. (2024) was changed to F1(k). However, k is the number of parking cars in the multi-story parking at that time. F1(k) is the parking location number which is available in order to k. This eliminates the need to check whether k is an available parking location.

(b) In the improved version, the cell pallet that last entered is moved to the available parking space each time a car exits the parking lot. But the cell pallet will be moved to a space with a small parking location number compared to before the improvement. However, comparing the post-improvement and pre-improvement situations, there are likely to be cases where the car moves closer to the exit and cases where it moves farther away. Which case is more prevalent will vary depending on the number of parked cars, but overall it is likely that the car moves closer to the exit more often, so it is believed that the post-improvement situation will be more efficient.

5. Experiment

It is assumed that the target multi-story parking lot is $m_1 = m_2 = m_3 = 10$. However, a car cannot park at the parking location of the coordinates (1, i, 1). And it cannot park at the top floor (10th) and the floor below (9th) because they are used for moving. In this section, the entering cost and exiting cost are derived and compared about experiments shown below. It is assumed that the moving left/right, up/down and front/backward time per a unit are the same. And they are treated as unit time costs. Also, for simplicity, parallel movement of cell pallets is not allowed. In other words, this assumes sequential control. The contents of the experiment are as follows. In an automated valet parking lot that shows the above from [1] to [9], assume that M* cars entered in order, after that, all cars exited in order of the ID number that used a uniform random number. In that case, the total entering and exiting time costs were derived and compared. Furthermore, total working time used to reduce the exiting time was derived and compared.

5.1 Experiment 1

Experiment 1 derives entering and exiting total time costs with using the automated valet parking of [1]. However, in the automated valet parking lot [1], the operation to reduce exiting time is not present.

5.1.1 Result 1

In entering algorism 4.2.1, No. k of the parking location of the entered cell pallet is decided by a uniform random number, and the entering time cost is derived by the coordinates (x, y, z) of No.k. The number of movement frames required to move the target cell pallet from the coordinates (1, 1, 1) to the coordinates (x, y, z) are as follows. First, the number of frames required to move the cell pallet at coordinates (1, 1, 1) to coordinates (1, m_2, 1) is m2-1, then the number of movement frames required to move the contents of coordinates (x, $m_2 - 2$, z), (x, $m_2 - 3$, z), ..., (x, y + 1, z) to the stack is $(m_2 - 2 - y)(m_2 - 2 - y + 1)$ (Figure 5). The number of moving frames

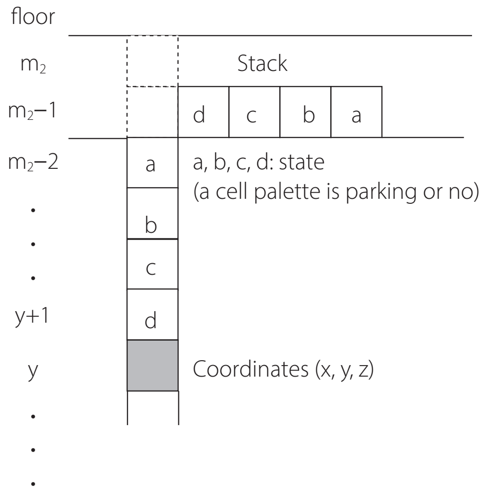

Figure 5: Upper cell palette (d, c, b, a) at coordinates (x, y, z) evacuated to stack

Note: The number of moving frames at that time is $(m_2 - 2\text{-}y)(m_2 - 2 - y + 1)$.

Source: Funase et al. (2024).

required to move the cell pallet waiting at the coordinates $(1, m_2, 1)$ to the coordinates (x, y, z) is $(x - 1) + (z - 1) + (m_2 - y)$. Finally, the number of frames required to move up the cell pallets of the coordinates $(x, m_2 - 2, z)$, $(x, m_2 - 3, z)$, ..., $(x, y + 1, z)$ that were evacuated to the stack is the same as the number of movement frames required to evacuate, so it is $(m_2 - 2 - y)(m_2 - 2 - y + 1)$. Therefore, the total entering time cost is:

$$2(m_2 - 2 - y)(m_2 - 2 - y + 1) + x + z + 2m_2 - y - 3 \qquad (1)$$

In exiting algorism1, the total exiting time is the same regardless of the order of exiting. Therefore, when the parking location number for parking is determined, the time cost for exiting the parking lot is derived in the same way. First, the number of movement frames required to move the contents of coordinates $(x, m_2 - 2, z)$, $(x, m_2 - 3, z)$, ..., $(x, y + 1, z)$ to the stack is $(m_2 - 2 - y)(m_2 - 2 - y + 1)$. The number of moving frames required to move the cell pallet at the coordinates (x, y, z) to the coordinates (x, m_2, z) is $m_2 - y$. The number of frames required to return the cell pallets that were evacuated to the stack is $(m_2 - 2 - y)(m_2 - 2 - y + 1)$. The number of movement frames required to evacuate the contents of coordinates $(m_1, m_2 - 2, 1)$, $(m_1, m_2 - 3, 1)$, ..., $(m_1, 1, 1)$ to the stack is $(m_2 - 2)(m_2 - 1)$. The number of movement frames required to move the cell pallets of coordinates (x, m_2, z) to the coordinates $(m_1, 1, 1)$ is $(m_1 - x) + (m_2 - 1) + (z - 1)$. Finally, the number of movement frames required to return the contents that evacuated to stack is $(m_2 - 2)(m_2 - 1)$. Therefore, the total is:

$$2(m_2 - 2 - y)(m_2 - 2 - y + 1) + 2(m_2 - 2)(m_2 - 1) + (m_2 - y) + (m_1 - x) + (m_2 - 1) + (z - 1) \qquad (2)$$

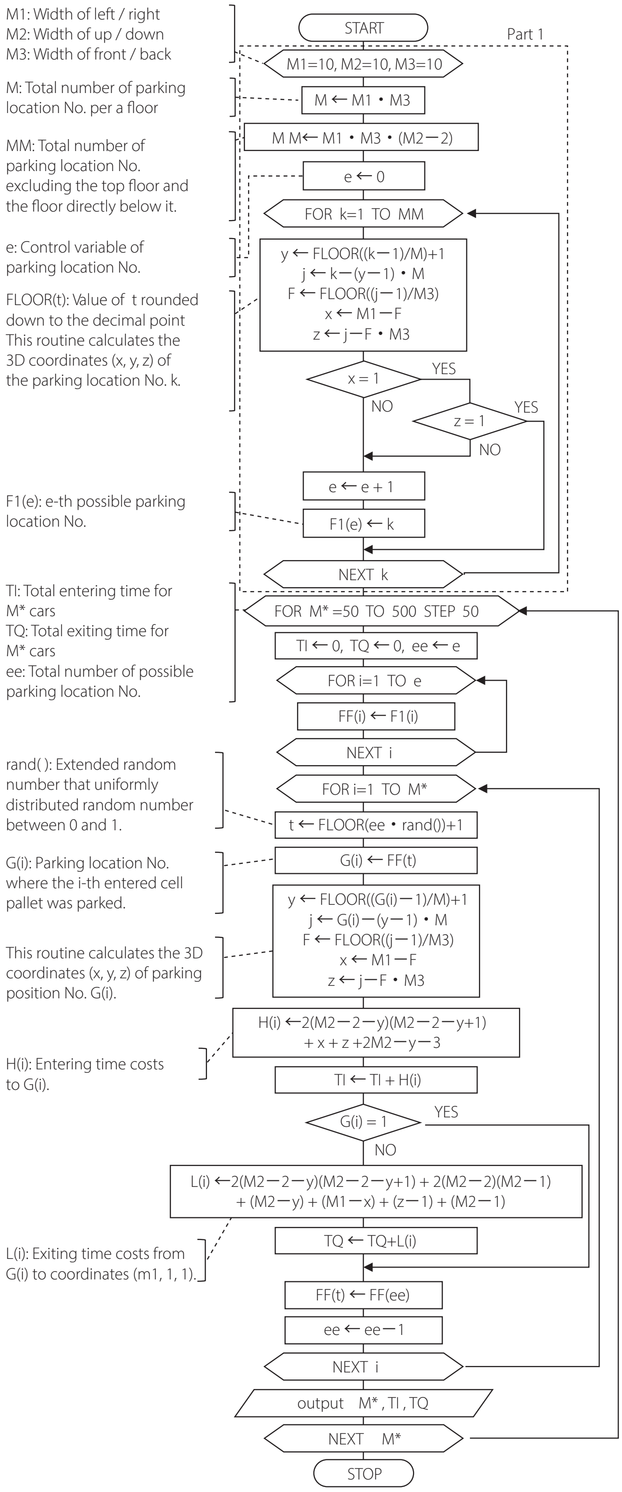

Figure 6: Flowchart that derives entering total time cost and exiting one for auto valet parking lot [1]

A flowchart that derives the entering total time cost and exiting one for the auto valet parking lot [1] is shown in Figure 6. Also, the entering total time cost and exiting one for the auto valet parking lot [1] are shown in Table 1. Furthermore, the automated valet parking lot [1] does not involve any work to reduce the time cost of exiting. And, each entering time cost H(i) and each exiting time cost L(i) was left, be-

Table 1: Entering and exiting total time costs for automated valet parking lot [1]

Number of entering cars	Entering total time costs	Exiting total time costs
50	3322	10520
100	6913	21275
150	9675	30913
200	12743	41519
250	16891	52865
300	19431	62507
350	22996	73066
400	24523	81931
450	29919	94347
500	33781	105605

cause the distribution can be calculated later.

5.2 Experiment 2

Experiment 2 derives entering and exiting total time costs with using the automated valet parking [2]. And derives the total operation time to reduce the exiting time cost.

5.2.1 Result 2

The entering algorism 4.2.1 is as described in Results 1. The difference between exiting algorism 4.3.2 and algorism 4.3.1 are shown below. In algorism 4.3.2,

(a) Since the cell pallet exits from the coordinates (x′, y′, z′), cell pallets on the y-axis to be evacuated are moved up to the top floor (ω) where the cell pallet is parked.
(b) And, after the car exited, the last entering cell pallet is moved to the coordinates (x′, y′, z′). However, this operation is wasteful. This is because if the last car that entered the parking lot is parked closer from the exit than the coordinates (x′, y′, z′), the exit will be far.

Figure 7 shows a flowchart for calculating the total entering time cost, the total exiting time cost, and the total operation time to reduce the exiting time cost for automated valet parking [2]. Also, Table 2 shows the total entering time cost, total exiting time cost, and the total operation time to reduce the exiting time cost for automated valet parking [2]. In addition, operations to reduce exiting time costs are usually performed in parallel with exiting ones. In addition, the operation required to move the last-entered cell pallet to coordinates (x′, y′, z′) after a cell pallet exited does not include the operation required to evacuate the cars that were located above the parking location (coordinates (x, y, z)) of the last-entered cell pallet. Also, the operation required to evacuate cars located on the upper floors at coordinates (x′, y′, z′) is not needed. This is because the cars that were evacuated from the upper floors when the car entered to the parking location at coordinates (x, y, z) are not returned until the cars parked at coordinates (x, y, z) have been moved to coordinates (x′, y′, z′). Also, the evacuated cars on the upper floors at coordinates (x′, y′, z′) will not be returned until the last entering car moves to coordinates (x′, y′, z′). In other words, the operation required for these two evacuations is included in the operation required for entering and exiting the parking lot, so there is no double cost. The reason to output each entering time cost H(i), each exiting time cost L′(i), and the work time K′(i) to reduce each exiting time is to enable a calculation of the distribution later. The reason why the total of entering time costs between Tables 1 and 2 differ slightly is because random numbers were used. In addition, the reason why the total of exiting time costs between Tables 1 and 2 were almost the same is because both used entering algorism 4.2.1, so the result of random numbers has almost no difference between

Table 2: Total entering time cost, total exiting time cost, and total operation time to reduce exiting time cost for automated valet parking [2]

Number of entering cars	Entering total time costs	Exiting total time costs	Total operation time to reduce exiting
50	3404	9844	1280
100	6732	20159	2621
150	9730	30788	3960
200	12450	40184	5154
250	16518	50315	6529
300	19598	62695	7877
350	23599	73746	9269
400	26382	82655	10456
450	28014	92871	11718
500	32789	103172	13198

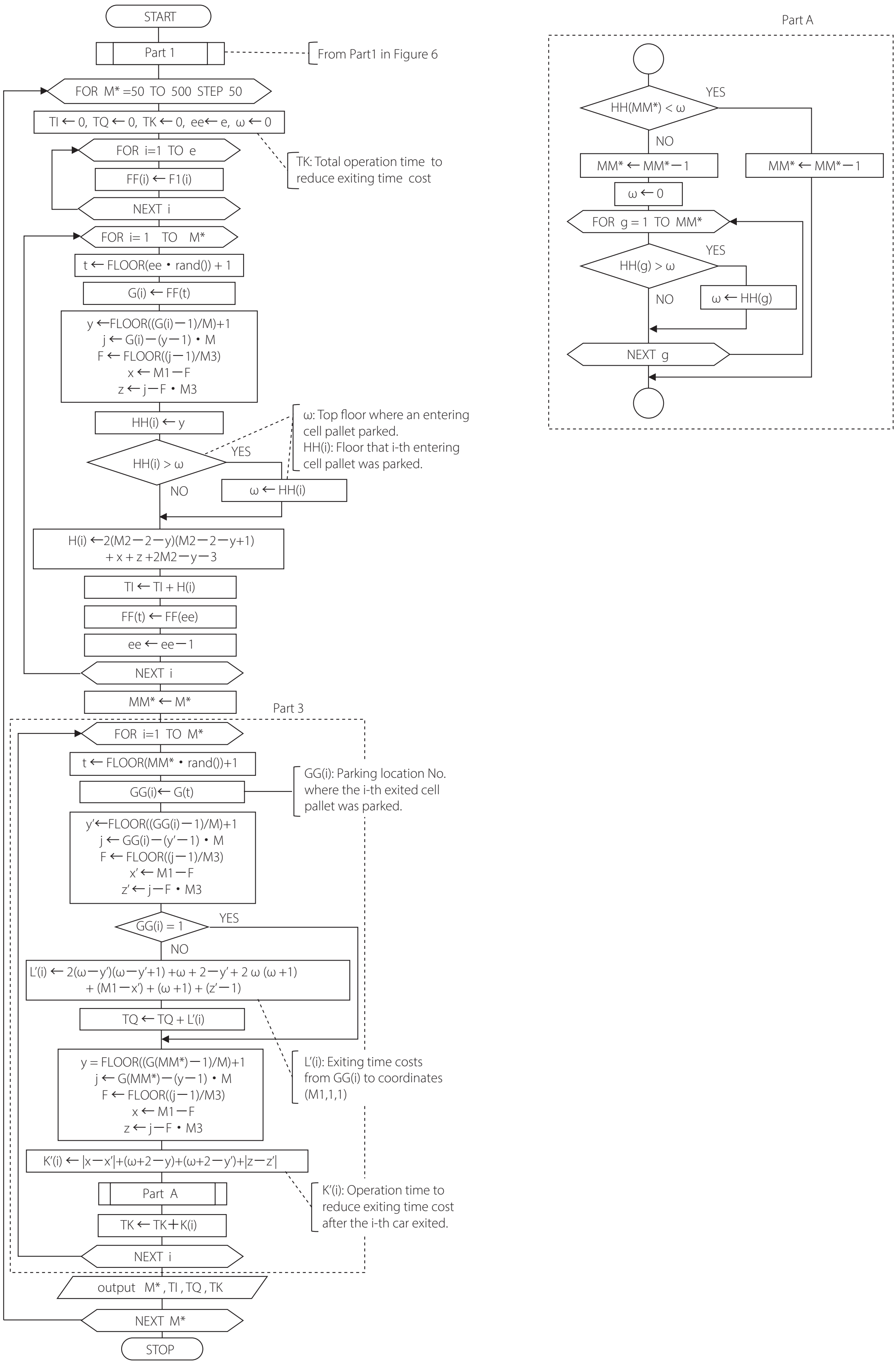

Figure 7: Flowchart for calculating total entering time cost, total exiting time cost, and total operation time to reduce exiting time cost for automated valet parking [2]

ω and $M_2 - 2$. However, when the number of entering cars is small, the maximum value of the random number generally does not become very large and the result has a difference between ω and $M_2 - 2$. However, when the number of entering cars increases, the maximum value of the random number becomes larger and the difference disappears.

5.3 Consideration 1

Consideration 1 concerns the efficiency of automated valet parking [3].

5.3.1 Result for Consideration 1

The entering algorism 4.2.1 is as described in the results of Experiment 1. The difference between exiting algorism 4.3.3 and algorism 4.3.1 are shown below. In exiting algorism 4.3.3, since the cell pallet exits from the coordinates (x′, y′, z′), the cell pallets on the y-axis to be evacuated move up to the top floor (ω) where a cell pallet is parked. Then, another point is that the cell pallets parked next to the exited parking location number are sequentially packed into the available coordinates (x′, y′, z′) after leaving the parking lot.

However, sequentially packing the cell pallets parked next to the parking location number into an available parking location means repeating evacuation and movement endlessly. As a result, the total amount of operation time required to reduce exiting time costs becomes too large. On the other hand, since it is not possible to expect a commensurate reduction in exit time costs, it was decided to exclude automated valet parking [3] from the list of efficient automated valet parking options. Similarly, it was decided to exclude automated valet parking [6] and automated valet parking [9].

5.4 Experiment 3

Experiment 3 derives entering and exiting total time costs using the automated valet parking [4]. Automated valet parking [4] has no operation time to reduce the exiting time cost.

5.4.1 Result 3

Figure 8 shows a flowchart for calculating the total entering time cost and the total exiting time cost for automated valet parking [4]. Also, Table 3 shows the total entering time cost and the total exiting time cost for automated valet parking [4].

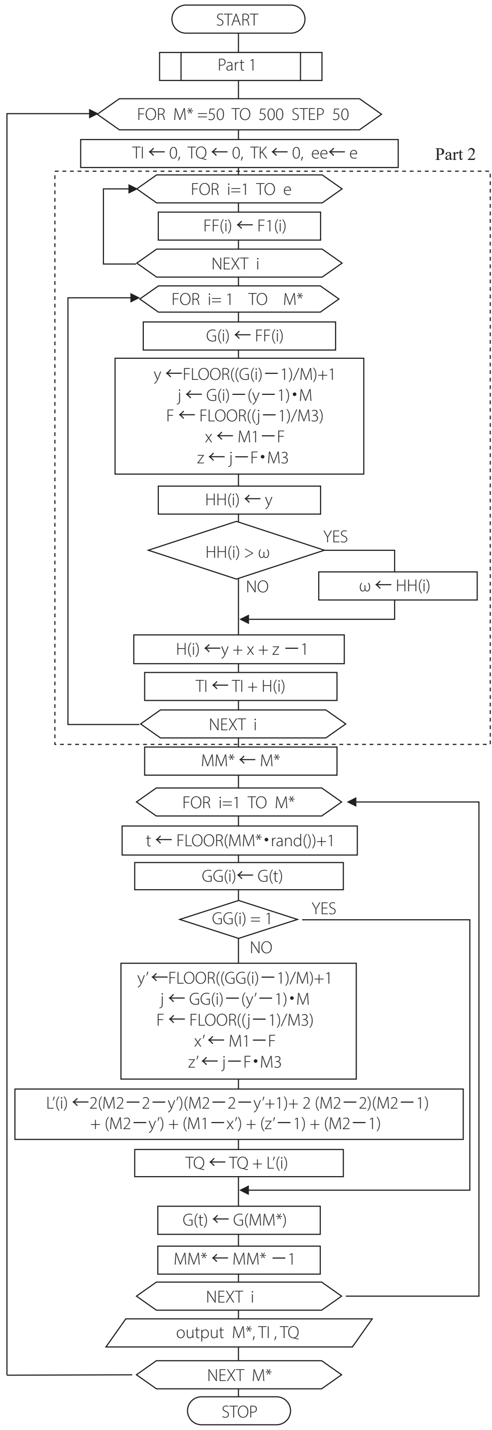

Figure 8: Flowchart for calculating total entering time cost and total exiting time cost for automated valet parking [4]

5.5 Experiment 4

Experiment 4 derives entering and exiting total time costs using the automated valet parking [5]. And derives the total operation time to reduce the exiting time cost.

5.5.1 Result 4

Figure 9 shows a flowchart for calculating the total entering time cost, the total exiting time cost, and the total operation time to reduce the exiting time cost for automated valet parking [5]. Also, Table 4 shows the total entering time cost, total exiting time cost, and the total operation time to reduce the exiting time cost for automated valet parking [5].

5.6 Consideration 2

Consideration 2 concerns the efficiency of automated valet parking [7].

Table 3: Total entering time cost and total exiting time cost for automated valet parking [4]

Number of entering cars	Entering total time costs	Exiting total time costs
50	2200	13751
100	3035	27988
150	5280	40568
200	6181	53330
250	8466	64665
300	9438	76160
350	11758	86450
400	12806	96886
450	15156	106331
500	16285	115916

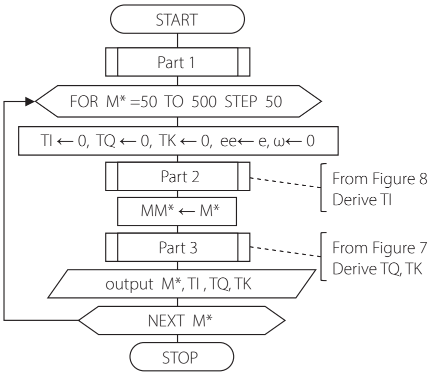

Figure 9: Flowchart for calculating total entering time cost, total exiting time cost, and total operation time to reduce exiting time cost for automated valet parking [5]

5.6.1 Result for Consideration 2

The entering algorism 4.2.3 of the automated valet parking [7] is similar to entering algorism 4.2.2 in that a car enters in order of the smallest number. The difference is that in entering algorism 4.2.2, the entering car parks in the parking location that are vacated by the exit, while in entering algorism 4.2.3, parking locations are allocated in order of the parking location number, and when it is full, make a "garbage collection." Therefore, when the number of car parking approaches full capacity, the operation time needed to reduce the exiting time cost will be greater for entering algorism 4.2.3. In addition, the total entering time cost is smaller with entering algorism 4.2.3 because it is simpler, but the total exiting time cost varies over a wider range with exiting algorism 4.3.3, so using entering algorism 4.2.2 is more efficient. Therefore, it was decided to exclude the automated valet parking [7] from the list of efficient automated valet parking options.

Similarly, it was decided to exclude the automated valet parking [8].

6. Conclusion

In the experiments and considerations for automated valet parking from [1] to [9], when M* cars entered the parking lot using uniform random numbers, the total entering time cost, the total exiting time cost, and the total operation time required to reduce the exiting time cost were calculated and compared. Among them, exiting algorisms 4.3.2 and 4.3.3

Table 4: Total entering time cost, total exiting time cost, and total operation time to reduce exiting time cost for automated valet parking [5]

Number of entering cars	Entering total time costs	Exiting total time costs	Total operation time to reduce exiting
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

included operations to reduce exiting time costs. However, since the total amount of operation time required to reduce the exiting time cost in exiting algorism 4.3.3 was enormous, it was decided to exclude the automated valet parking [3], [6] and [9] as a candidate for efficient automated valet parking. As a result, it was found that among the candidates, the automated valet parking [5] was the most efficient.

A future challenge will be to propose an even more efficient automated valet parking system. The points that could not be taken into consideration this time are the cases where the car is parked in parking location No. 2 or a parking location above it, the cases where the car is parked in parking location No. $m_3 + 1$ or a parking location above it and the cases where the car is parked above parking location No.1. In these cases, because exiting will be easier than with the exiting algorism used this time, a different approach should be taken from the exit algorism for other parking location numbers.

It is also necessary to reconsider what efficient automated valet parking looks like. From the customer's point of view, it does not matter about the entering time cost and how long the operation time is reduced for the exiting time cost. Customers only concern is about exiting time efficiency. This is because customers complete the entry procedures at the parking lot entrance, leave their car park to the staff, and leave. So what about the parking lot manager? The smaller entering time costs and operation time required to reduce exiting time costs, the more the electricity bill and system operating time can be reduced. Of course, if exiting times are smaller, electricity costs and other costs can also be reduced, so the issue is how to reduce the total of these three costs.

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