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Proposal of An Auto Valet Parking to Maximize Space Utilization Efficiency in Three-Dimensional Area

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***Abstract*— There is a multi-story car parking was proposed as parking in main cities to maximize space utilization efficiency in three-dimensional area. This multi-story car parking has only parking space, so no exclusive space for passage and slope. Therefore, a car moves to target space through parking spaces. And the car does not drive by driver, is moved by electric pallet what called cell-pallet. A cell pallet is a rectangular parallelepiped pallet that can accommodate one passenger car. The parking is configured by skeleton of pole like a jungle gym in a park. The cell-pallet moves to left-right, up-down and forward-backward in the parking. Electric gear wheels that take into consideration stable movement are effectively placed on this cell pallet to realize safe and efficient movement of the vehicle. Furthermore, on odd-numbered floors, only left-right and up-down movement is possible, and on even-numbered floors, only forward-backward and up-down movement is possible. If left-right and forward-backward movements were to be achieved on the same floor, the left-right and forward-backward poles would get in the way, so the floors are divided maximize space utilization efficiency in three-dimensional area.**

However, there is no description of how to entering method and exiting method of the multi-story car parking. In this paper, in order to propose automated valet parking that makes maximum use of this three-dimensional space, we propose a method for entering and leaving the parking lot.

***Index Terms*— Automated valet parking, Cell-pallet, Entering method, Exiting method, Multi-story car parking**

I. Introduction

A parking lot [1] is a place for parking a car and can be roughly divided into a flat parking lot and a multi-story parking lot [2]. The former is a one-stage parking lot installed on the ground. Other than partitioning the parking space visibly with a line, it requires no special equipment and can be maintained at low cost. Therefore, it is widely installed in regions with few land restrictions. The latter can be further divided into drive-in and mechanical types. Each variety of multi-story car park [3] has an advantage in terms of high land use efficiency and the design of the facility changes according to user attributes (residents, temporary users) and their composition. In addition, the parking lot is designed and planned in consideration of harmony with the environment and the safety and convenience of use. Mechanical car park [4]-[6] is a type of parking lot where cars are vertically stacked up in multiple stages. There are various types from two stage car parks to elevator or vertical-circulation car parks. The former is simpler, but first stage should be emptied for the second stage to be used. The latter does not have such restriction and gives more parking spaces for the same square footage. However, they require special equipment and machines, which increases installation and operation costs. Drive-in car park allows drivers to drive their cars to empty parking space [7]. Compared to the mechanical type, the self-propelled type requires driving in the parking lot, so some people find it troublesome. However, unlike the mechanical type, the self-propelled type eliminates the impression of waiting while driving by itself, so that the subjective time cost is reduced. In addition, since the car can be freely taken in and out without the intervention of other people such as the staff, there is a merit for those who find it troublesome to interact with the staff during the parking procedure. However, it is inferior to the mechanical type in terms of space utilization efficiency since the number of parking spaces per site area is smaller than that of the mechanical type. 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 [8]. These are parking lots that automatically entrance and exit by self-drive. But that way has not yet 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 scale of multi-story car parking grow up, it is pointed out that the systems have problems such as accidents (in-park movement, theft), searching for parking spaces, boarding/deboarding at narrow designated places, and difficulty in using for beginners and elderly people. To solve these issues, authors proposed the automated valet parking using original automatic pallet [9]. Also, proposed parking location determination method to realize high time-efficient exit operations [10]. Furthermore, proposed how to move automatic pallets to improve the time efficiency of exit operation [11], and clarified how much the time efficiency of exit operation is improved by simulations [12]. In this research, the multi-story car parking that makes the most of the three-dimensional space proposed in [13] will be focused. This multi-story car parking has purpose to maximize number of parking cars. Multi-story drive-in car parks 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 parking space, additional spaces such as driving lane, slopes to connect adjacent floors and steps or elevators for drives are required. It also requires special large equipment which are most of the time expensive. Finally, although it has higher efficiency in space usage, the number of vehicles that can be accommodated is small. [13] 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 large capacity and high parking efficiency per floor area.

However, there is not mentioned in the paper [13] how to entrance and exit movement. In this paper shows how to entrance and exit for proposing an auto valet parking to maximize space utilization efficiency in three-dimensional area.

Ⅱ. CELL PALLET

The cell pallet is an electric pallet (Fig.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. The operator in the control room operates the pallet movement. The pallet's floor thickness is 20 to 30 cm. Its shape is rectangular with four corners trimmed for the gear wheels to be deployed as necessitated.

A total of 20 electric gear wheels (4 on each side and 1 on each corner) are installed on the pallet. 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. To prevent interference between a vertical pole and the electric gear wheel deployed on the side of the pallet, a spring is inserted between the fixed parts of the electric gear wheel, and when the pressure due to the movement reaches a certain designated magnitude, the gear wheel will retract into the pallet. If the retracted gear wheel cannot be redeployed due to deterioration of the spring, a sensor that monitors the extension of the spring notifies the operator in the control room. A wheel stopper is installed at the front and rear of the cell pallet to hold the tires of the loaded vehicles securely. When the cell pallet is not in use, the wheel stopper is retracted in the cell pallet. When the pallet is in use, the wheel stopper is deployed to hold the wheels of the loaded vehicles longitudinally from the front and the rear.

Ⅲ. THE TARGET MULTI-STORY CAR PARKING

The target multi-story car parking [13] consists of a pole skeleton (Fig.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 exit is at front row 1st right end. The mechanism of each operation will be described below.

A. Left-Right Movement

Fig.3 shows a conceptual diagram of the left-right movement of the cell pallet. Also, this shows the location of parking car. And the No. is put on each parking location. During the left-right movement, only the electric gear wheels on the left-right sides of the pallet are deployed and the others are retracted in the pallet. The combination of the deployed gear wheel and the gear racks embedded in the horizontal poles allows the stable left-right movements of the pallet. Fig.4 and Fig.5 show the combination of the gear wheel and the gear rack in plan and side views respectively. Fig.6 shows the plan view of the entire cell pallet. When the gear wheels come to a vertical pole, the one with direct contact with the pole is retracted into the pallet due to the pressure generated by the contact; the others remained deployed and generate the power for continuous left-right movement. By operating these steps for the four gear wheels on the side, the pallet can pass through the vertical pole.

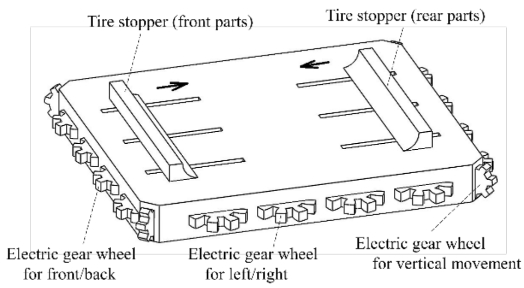


Figure 1 Structure of the cell pallet

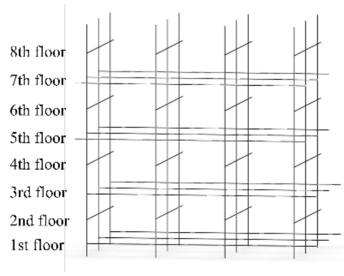


Figure 2 Skelton structure of proposed car park: 3x8x2.

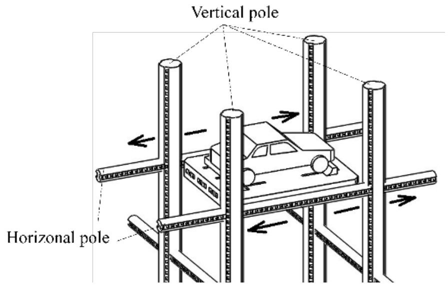


Figure 3 Schematic image of longitudinal movement

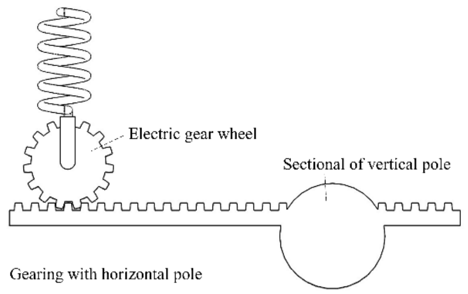


Figure 4 Electric gear and gear rack in longitudinal pole (plan view)

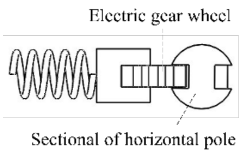


Figure 5 Electric gear and gear rack in longitudinal pole (side view)

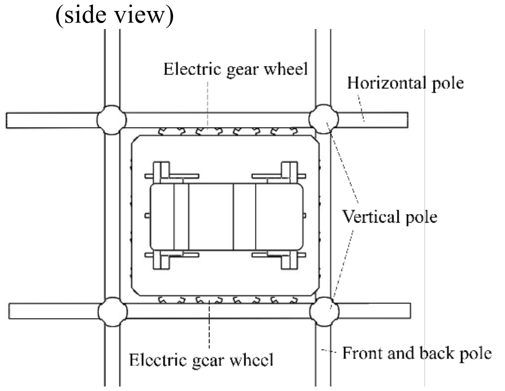


Figure 6 Plan view of longitudinal movement

B. Vertical Movement

Fig.7 and Fig.8 respectively show a conceptual diagram and a plan view of the vertical movement of the pallet. The pallet is moved to a position where its four corners face the vertical poles. The electric gear wheels on the long and short sides are retracted and those on the four corners are deployed to be combined with the gear racks in the vertical poles, which allows the cell to move vertically. The combining mechanism is similar to that of left-right movement, except for in the case of vertical movement, there exists no poles to hinder the movement. Fig.9 shows the cross-sectional structure of the vertical pole.

C. Transverse Movement

Fig.10 and Fig.11 respectively show a conceptual diagram and a plan view of the transverse movement of the pallet. The gear wheels on the long sides and the four corners are retracted into the pallet and those on the short sides are deployed to fit with the gear racks in the horizontal poles. The steps to pass over the vertical poles in transverse movement is same as those in longitudinal movement.

D. Direction Change

In the multi-story car park shown in Fig.2, pallets on the first floor can move in left-right and vertical directions but not in the transverse direction. On the second floor, transverse and vertical movements are possible, but left-right movements are not possible. In either case, vertical movement by one floor is necessary. Fig.12 which magnifies the part of Fig.2 shows that transverse poles which are positioned higher than the pallet allows the left-right movement on the first floor and that left-right poles on the third floor which are positioned higher than the pallet on the second floor allows the pallet on the second floor to move transversely. The combinations of these conditions allow the pallet to move in every direction in the proposed parking.

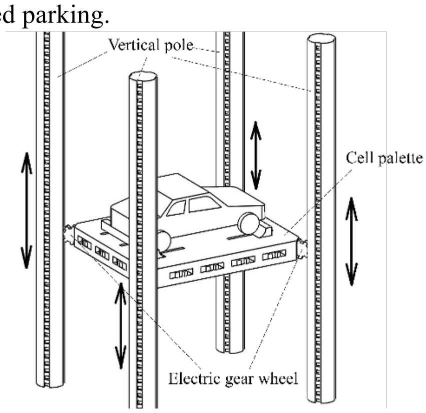


Figure 7 Schematic image of vertical movement

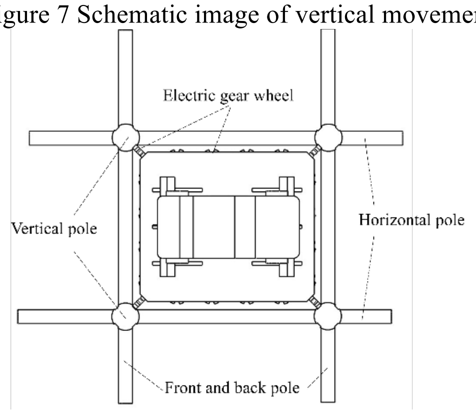


Figure 8 Plan view of vertical movement

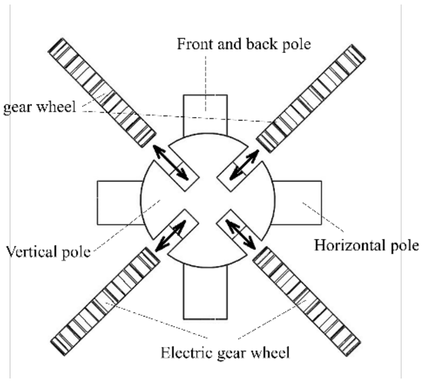


Figure 9 Cross section view of electric gears and vertical pole

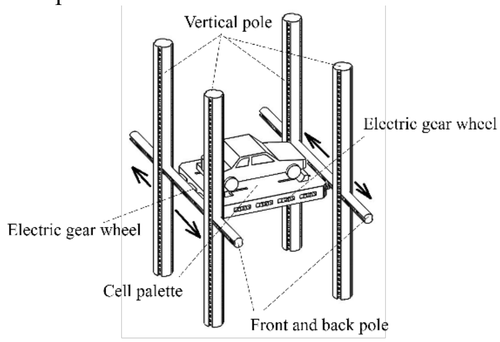


Figure 10 Schematic image of transverse movement

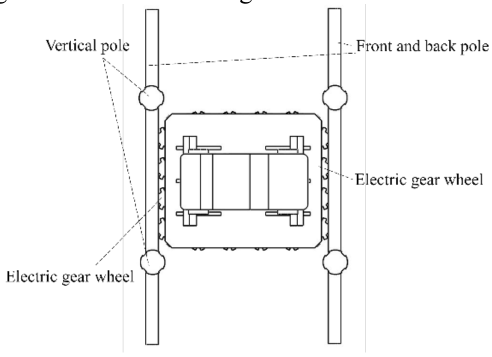


Figure 11 Plan view of transverse movement

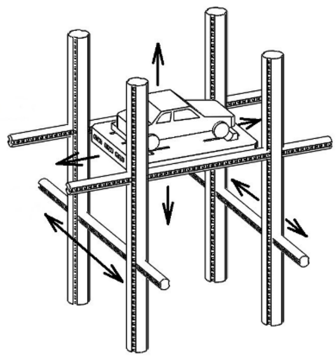


Figure 12 Close-up view of three-axis movement

□. Algorithm Of Entering Procedure

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

How to move the pallet to a parking location in the proposed multi-story parking is below. At first, one unit of parking space is size of cell pallet. The parking location of target is shown by coordinates (x,y,z). The x is position of left and right way, and it is shown xth position from end of left. The y is position of up and down way, and it is showing the yth floor. The z is position of forward and backward way, and it is showing the zth position from front side. When a car enters in the parking, the coordinate of first location for parking is (1,1,1). So, the entry algorithm is an algorithms of moving cell pallet from (1,1,1) to (x,y,z). The parking location No. is serial number that is set to each parking location from 1st floor to top floor. And the parking location No. which is directly above floor from parking location No.j is m_1m_3+j. The entered car is parked with order of small No. parking location which is available. For example, on the first floor, parking locations are allocated as shown in Fig.13. However, in the end of left row, do not park at coordinate (1,i,1)(i=1,2, • • • , m_2). m_1 is the number of parking cars per a line and m_2 is the number of floors on the top floor. And m_3 is the number of parking cars per a row. Details are shown in Fig.14.

Three dimensional coordinate (x,y,z) of the parking location No.k is shown below.

$$\begin{aligned} &M=m_1 \cdot m_3 \\ &y = \mathrm{FLOOR}((k-1)/M)+1 \\ &j = k-(y-1) \cdot M \\ &F = \mathrm{FLOOR}((j-1)/m_3) \\ &x = m_1-F \\ &z = j-F \cdot m_3 \end{aligned} \qquad (1)$$

However, when x is positive FLOOR(x) is value with decimal places removed for x. The top floor (m_2) of the multi-story parking and the floor directly below it (m_2-1) are used for the movement of cell pallets. Also it is used as a stack to temporarily remove cell pallets that get in the way when the target cell pallet exit. Therefore, the maximum number of cars that can be accommodated in the target multi-story parking is ($m_1 \cdot m_3$ - 1) (m_2 - 2). Next, the entering car algorithm for moving the cell pallet from the coordinates (1, 1, 1) to the coordinates (x, y, z) is shown below.

A. Algorithm 1

Operation (1) : When a customer's car arrived at the parking entrance, entry reception is performed, then a ID card is given to driver. On the card, a ID number d has printed, and d becomes to d+1 just before the card is given. Here, initial value of d is 0. (that is mean, number of parking car is 0) In addition, when business hours are over, d will be initialized to 0.

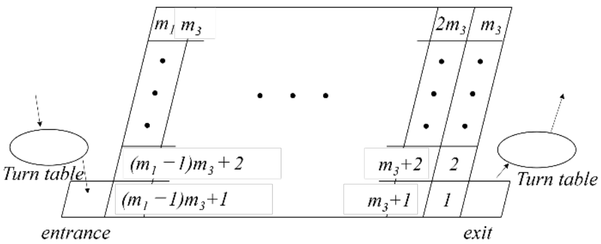


Figure 13 Parking location No. on first floor

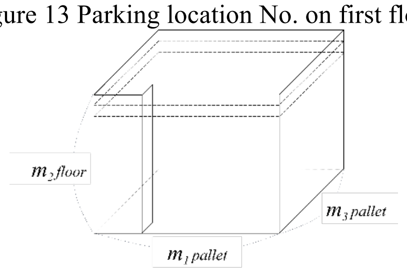


Figure 14 Image of the target multi-story parking

(However, Do not park on the top floor, next low floor from top floor and at coordinates (1,i,1))

Operation (2) : k ← k + 1

k is parking location No. and initial value (number of parking car is 0) of k is 0. Parking location No. which are coordinates (1, i, 1), m_2th floor and m_2-1th floor does not use.

Operation (3) : A(d) ← k

A(d) is parking location No. of the cell pallet that puts customers car taken a card of ID number d on.

Operation (4) : Find the coordinate (x,y,x) of parking location No.A(d).

Operation (5) : B(x,y,z) ← d

B(x,y,z) is the ID number of the car on the cell pallet that parked on the three dimensional coordinate (x,y,z) of parking location No.k. Also, the initial value of B(x,y,z) is 0 and shows that cell pallet does not park on coordinate (x,y,z).

Operation (6) : Go up the cell pallet parked on coordinate (1,1,1) to yth floor.

Operation (7) : If y is an even number, proceed to Operation(8). If y is an odd number, proceed to Operation(9).

Operation (8) : Move backwards to z, then go up just one floor to (y+1)th floor. Next, move right to x, then go down just one floor and park on yth floor.(Fig.15) Proceed to Operation (10).

Operation (9) : Move right to x-1, then go up just one floor to (y+1)th floor. Next, move backwards to z, then go down just one floor to yth floor, then move right just one space and park. (Fig.16)

Operation (10) : End.

V. Exit Algorithm

To exit the car parking, the customer goes to the exit of the parking and presents the ID number card. From ID number find the parking location No. of the cell pallet on which the customer's car is placed then the cell pallet is moved to coordinate (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 exit to the exit. In other words, this is an algorithm that find the coordinates (x, y, z) from the ID number and moves to the coordinates (m_1, 1, 1). Specifically, it is shown below.

A. Algorithm 2

Operation (1) : By submitting the ID number card, the written ID number d is read out, and the parking location number i of the cell pallet on which the customer's car is placed is exited from A(d)=i. Furthermore, the current number of parking cars in the multi-story parking lot is assumed to be k.

Operation (2) : Find the coordinate (x',y',z') of parking location No.i.

Operation (3) : Find the coordinate (x,y,z) of parking location No.k.

Operation (4) : If the coordinates (x', y', z') = coordinates (m_1, 1, 1), proceed to operation (12). If not, proceed to Operation (5).

Operation (5) : j ← i-(y'-1) • m_1 • m_3

j' ← k-(y-1) • m_1 • m_3

If j>j', T ← y-1. If not T ← y.

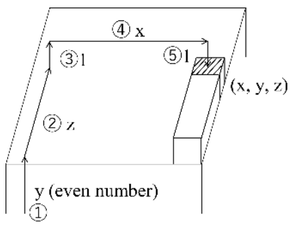


Figure 15 Flow of the operation (8) in the *algorithm 1*

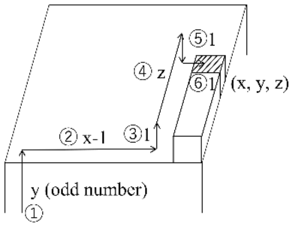


Figure 16 Flow of the operation (9) in the *algorithm 2*

Operation (6) : Create a stack on the T+1 or T+2 floor near the coordinates (x', T, z') and temporarily evacuate the cell pallets parked at coordinates (x',T,z'),(x',T-1,z'),(x',T-2,z'),...,(x',y'+1,z'). However, operations (6) and (7) are simulated on the computer immediately before stack generation, so that the cell pallet in operation (7) does not block the passage when moving, and operation (6) can be executed. This can be achieved by finding a stack like this.

Operation (7) : The cell pallet parked at coordinates (x',y',z') is moved to coordinates (m_1,y+2,1).

Operation (8) : Pop up the stack in order and put back to coordinates(x',y'+1,z'),(x',y'+2,z'), ・・・,(x',T,z') .

Operation (9) : Create a stack on the y+1 or y+2 floor near the coordinates (m_1,y,1) and temporarily evacuate the cell pallets parked at coordinates (m_1,y,1),(m_1,y-1,1),(m_1,y-2,1),...,(m_1,1,1). However, operations (9) and (10) are simulated on the computer immediately before stack generation, so that the cell pallet in operation (10) does not block the passage when moving, and operation (9) can be executed. This can be achieved by finding a stack like this.

Operation (10) : The cell pallet parked at coordinates (m_1,y+2,1) is moved to coordinates (m_1,1,1) and exit.

Operation (11) : Return the cell pallet which had evacuated to stack to coordinates (m_1,1,1),(m_1,2,1), ・・・,(m_1,y,1).

Operation (12) : B(x',y',z')←B(x,y,z)

Move the cell pallet where parked at the coordinates (x,y,z) to the coordinates (x',y',z'). Become to k=k+1 then end. In addition, the stack in this paper is generated from a series of cells in a three-dimensional structure.

B. Example 1

Consider the stack that will be generated by operation 6 of the algorithm 2. This time, it is necessary to generate the stack so that it can be executed the operation 7. For example, when assume coordinate (x',T,z')=(3,4,3), coordinate (x,y,z)=(2,4,2), m_1=m_3=5 and m_2=6, the cell pallets parked at the coordinates (3,4,3), (3,3,3), (3,2,3) are sequentially moved to the coordinates (5,6,3), (5,5,3), (4,5,3).

Then, a stack that can be pushed down to the coordinates (5,6,3), (5,5,3),(4,5,3) can be created. This stack is searched just before operations using a computer simulation. Fig.17 shows this situation. The shaded area is generatable spaces as stack. Furthermore, in the case of a blank space, a stack may obstruct the movement of the cell pallet, but it is also possible to decide in advance the movement of the cell pallet

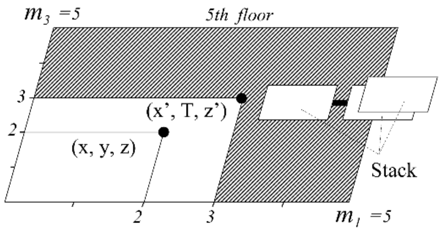


Figure 17 Example of generated stack by operation (6) in the algorithm 2.

and use computer simulation to search for a stack that does not become an obstruction.

VI. Preparation For The Experiment

The target multi-story car parking is m_1=m_2=m_3=10. However, the parking location at coordinates (1,i,1)(i=1,2,...,m_2), the top floor (10th floor) and the floor directly below the top floor (9th floor) are for moving cell pallets. Therefore, a car can't be parked there. At this time, it assume that M* cars enter the car parking one after another, and then all the cars exit the car parking in the order of uniform random numbers. The time cost required for this process will be experimentally determined and compared. The time costs are the enter time cost (time cost required for entering) and the exit time cost (time cost required for exiting). However, the moving time for one unit from side to side, top and bottom, and forward and backward of the cell pallet is all the same, and this is taken as the unit time cost. Furthermore, the execution time of the computer simulation required to generate the stack is less than 1 second, which is insignificant compared to the time required to move the cell pallet, so it will not be considered. Furthermore, parallel movement of cell pallets is not allowed. Assume sequential control. Regarding the entering method and the exiting method, the following types are considered.

A. Type of The Entering Method

(1) Type 1

The parking position number for entering is determined using a uniform random number. Also, find the corresponding coordinates (x,y,z) and go up the cell pallet parked at coordinates (1,1,1) to the m_2 floor (coordinates (1, m_2,1)). Furthermore, the cell pallets parked at the coordinates (x,m_2-2,z),(x,m_2-3,z),...,(x,y+1,z) are temporarily evacuated to the stack, Then, move the cell pallet parked at coordinates (1,m_2,1) to coordinates (x,y,z). Then, the cell pallets that were evacuated to the stack are returned to their original coordinates (x,y+1,z),(x,y+2,z),...,(x, m_2-2,z).

(2) Type 2

The entering method proposed in this paper (Algorithm 1).

B. Type of The Exiting Method

(1) Type 1

The parking position number where the next exiting cell pallet is parked is determined using a uniform random number. Also, find the corresponding coordinates (x,y,z). Then, the cell pallet with the coordinates $(x,m_2\text{-}2,z)$, $(x, m_2\text{-}3,z)$, ..., (x,y+1,z) is temporarily evacuated to the stack. Then, move the cell pallet parked at coordinates (x,y,z) to coordinates (x,m_2,z) and return the cell pallet that was evacuated to the stack to its original coordinates. Then, the cell pallet with the coordinates $(m_1, m_2\text{-}2,1)$, $(m_1, m_2\text{-}3,1)$, ..., $(m_1, 1,1)$ is evacuated to the stack. Next, the cell pallet with the coordinates (x,m_2,z) move to the coordinates $(m_1,1,1)$. Then, move it to the exit. After that, the cell pallet that was evacuated to the stack is returned to its original coordinates.

(2) Type 2

The exiting method proposed in this paper (Algorithm 2).

Note that for uniformly distributed random numbers in the interval (0,1), the accuracy of RND(1) is not very good, so the following extended form rand() is used in the experiment [14].

C. Uniform Random Number With Extended Rand()

Use the C language built-in function rand() and divide rand()+0.5 by RAND_MAX+1 to distribute it evenly without being biased toward either end. However, since the value of RAND_MAX is relatively small depending on the processing system, a uniform random number is calculated using the values of multiple rand() functions as follows.

```
double urand(){
  double m, a;
  m=RAND_MAX+1;
  a=(rand()+0.5)/m;
  a=(rand()+a)/m;
  return (rand()+a)/m;
}
```

VII. Experiment 1

Using the Type 1 entering method and Type 1 exiting method, calculate the total entering time and total exiting time for each case when the number of cars m* is increased to 10, 30, ..., 250. However, it is assumed that the stack can be generated on the m_2-1st floor.

(result)

Fig.18 shows a flowchart for calculating the total entering time and total exiting time. In the type 1 warehousing method, the warehousing time cost (number of frames moved by the cell pallet) is calculated from the coordinates (x, y, z) of the parking position No. k of the cell pallet determined by uniform random numbers. Specifically, the number of frames required to move the target cell pallet from the coordinates (1, 1, 1) to the coordinates (x, y, z) is 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 m_2-1. Next, the number of frames required to evacuated the cell pallet at coordinates $(x, m_2\text{-}2,z)$, $(x, m_2\text{-}3,z)$,..., (x,y+1,z) to the stack is $(m_2\text{-}2\text{-}y)(m_2\text{-}2\text{-}y\text{+}1)$ (Fig.19). And the number of frames required to move the cell pallet waiting at the coordinates $(1, m_2,1)$ to the coordinates (x,y,z) is $(x\text{-}1)+(z\text{-}1)+(m_2\text{-}y)+2$. Finally, the number of frames to return the cell pallet that was evacuated to the stack at the coordinates $(x, m_2\text{-}2,z)$, $(x, m_2\text{-}3,z)$,..., (x,y+1,z) is the same as the number of frames required when evacuating. So it is $(m_2\text{-}2\text{-}y)(m_2\text{-}2\text{-}y\text{+}1)$. Therefore, the entering time cost is

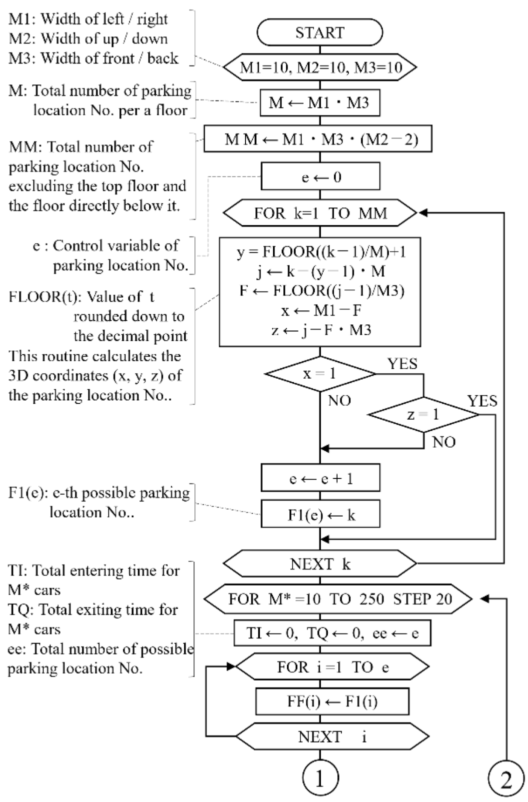
$$2(m_2\text{-}2\text{-}y)(m_2\text{-}2\text{-}y\text{+}1)\text{+}x\text{+}z\text{+}2m_2\text{-}y\text{-}1. \qquad (2)$$

Furthermore, using type 1 as the exiting method means that the total exiting time is the same regardless of the order of exiting. Therefore, when the parking position number for entering is determined, the exiting time cost for the cell pallet is determined in the same way. First, the number of frames required to evacuated the cell pallet at coordinates $(x, m_2\text{-}2,z)$, $(x, m_2\text{-}3,z)$,..., (x,y+1,z) to the stack is $(m_2\text{-}2\text{-}y)(m_2\text{-}2\text{-}y\text{+}1)$. And, the number of frames required to move the cell pallet at coordinates (x, y, z) to coordinates (x, m_2, z) is $(m_2\text{-}y)$. The number of frames required to return to the cell pallet of evacuation to the stack is $(m_2\text{-}2\text{-}y)(m_2\text{-}2\text{-}y\text{+}1)$.

The number of frames required to return the cell pallet that was evacuated to the stack is $(m_2\text{-}2\text{-}y)(m_2\text{-}2\text{-}y\text{+}1)$. The number of frames required to evacuate the cell pallet of the coordinates $(m_1, m_2\text{-}2,1)$, $(m_1, m_2\text{-}3,1)$,..., $(m_1,1,1)$ to the stack is $(m_2\text{-}\ 2\ )(m_2\text{-}1)$. The number of frames required to evacuate the cell pallet of the coordinates $(m_1, m_2\text{-}2,1)$, $(m_1, m_2\text{-}3,1)$,..., $(m_1,1,1)$ to the stack is $(m_2\text{-}\ 2\ )(m_2\text{-}1)$. The number of frames required to move the cell pallet at coordinates (x,m_2,z) to coordinates $(m_1,1,1)$ is $(m_1\text{-}x)+(m_2\text{-}1)+(z\text{-}1)+2$. Finally, the number of frames required to return the cell pallet that was evacuated to the stack is $(m_2\text{-}2)(m_2\text{-}1)$. Therefore, the total is

$$2(m_2\text{-}2\text{-}y)(m_2\text{-}2\text{-}y\text{+}1)+2(m_2\text{-}2\ )(m_2\text{-}1)+(m_2\text{-}y)+(m_1\text{-}x) +(m_2\text{-}1\ )+(z\text{-}1)+2. \qquad (3)$$

The results of Experiment 1 are shown in Table 1.



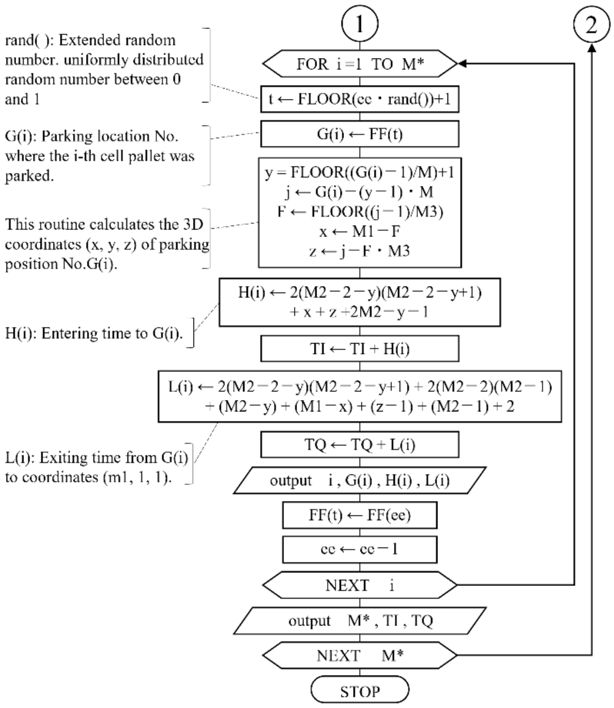


Figure 18 Flow chart of the Experiment 1

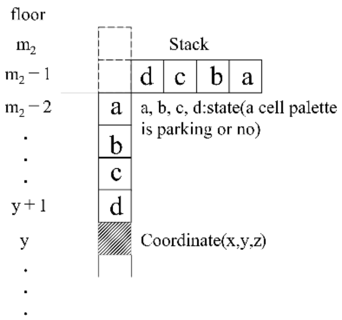


Figure 19 The upper cell palette (d, c, b, a) at coordinates (x, y, z) is evacuated to the stack. The number of moving frames at that time is $(m_2\text{-}2\text{-}y)(m_2\text{-}2\text{-}y+1)$.

Table 1 Total time of entering and exiting for number of m* cars in Experiment 1

Number of m* cars	Entering total times	Exiting total times
10	678	2114
30	1937	6243
50	3405	10607
70	4907	14969
90	6382	19318
110	7731	23575
130	9207	27931
150	10330	31906
170	11593	36039
190	13160	40466
210	14353	44561
230	15875	48997
250	17438	53440

Ⅷ. EXPERIMENT 2

Using the Type 2 entering method and Type 2 exiting method, calculate the total entering time and total exiting time for each case when the number of cars m* is increased to 10, 30, ..., 250. However, it is assumed that the stack can be generated on the floor directly above the top floor where the cell pallets are parked.

(result)

The Fig.20 shows a flowchart for calculating the total entering time and total exiting time. In Type 2 entering method, cars are parked in the order of parking position numbers. However, parking will not be allowed on the top floor (m_2 floor), the floor directly below it (m_2-1 floor), and the position at the coordinates (1,i,1) (i=1,2,..., m_2). Furthermore, the three-dimensional coordinates (x, y, z) corresponding to the parking position number are derived, and the cost of moving the cell pallet from the coordinates (1, 1, 1) to the coordinates (x, y, z) is calculated. First, moving to the right takes x-1 frames, moving upwards takes y-1 frames, and moving backwards takes z-1 frames. But it is necessary to go up and down one floor to switch between the right direction and the back direction. Therefore, the total is

$$y+z+x-1. \qquad (4)$$

The exiting method is type 2. The order of exiting is in the order of ID numbers determined using uniform random numbers. Let the three-dimensional coordinates of the parking position number where the cell pallet selected at this time is parked be (xp, yp, zp). Cell pallets are moved on the floor directly above the top floor (MC floor) where cell pallets are parked. It is (MC+1st floor) and the floor above it (MC+2nd floor). Furthermore, in order to create the passage for the cell pallets parked at the coordinates (xp, yp, zp) , the cell pallets parked at the coordinates (xp, yp+1, zp), (xp, yp+2, zp),..., (xp,MC,zp)are evacuated to the stack. Similarly, in order to move the cell pallet from the coordinates (xp, yp, zp) to the coordinates (m_1,1,1), evacuate the cell pallet at the coordinates (m_1,1,1),(m_1,2,1),..., (m_1,MC,1)to the stack. The coordinates (m_1,1,1) is exit position. The number of moving frames in order to move the cell pallet where parked at coordinates (xp, yp, zp) to coordinates (m_1, 1, 1) is as follows.

Step 1

Number of moving frames to evacuate the cell pallet with coordinates (xp,yp+1,zp), (xp,yp+2,zp), ..., (xp,MC,zp) to the stack is (MC -yp)・(MC-yp+1).

Step 2

Number of moving frames to coordinates (m_1, MC+2, 1) is

(m_1-xp)+(MC+2-yp)+(zp-1)+2.

Step 3

Number of moving frames to return the cell pallet that was evacuated to the stack is (MC-yp)・(MC-yp+1).

Step 4

Number of moving frames to evacuate the cell pallet with coordinates (m_1,1,1), (m_1,2,1),..., (m_1,MC,1) to the stack is MC・(MC+1).

Step 5

Number of moving frames to move to coordinates (m_1,1,1) is (MC+1).

Step 6

Number of moving frames to return the cell pallet of the stack to its original state: is MC・(MC+1).

The total of these is

$$2(MC-yp)(MC-yp+1)+(m_1-xp)+(MC+2-yp)+(zp-1)+2\,MC\cdot(MC+1)+MC+3. \quad (5)$$

Note that the value of MC changes depending on the exiting. This will be explained in detail below. The initial value of MC is the y coordinate of A(M*). If a cell pallet with coordinates (xp, yp, zp) is moved to exit, B(xp, yp, zp) coordinate is 0, and the value of C(xp, zp) coordinate may decrease. If it actually decreases, there is a possibility that the MC value will also decrease, so need to check this. Table 2 shows the total time of entering and exiting for m* cars.

Table 2 Total time of entering and exiting for m* cars in Experiment 2

Number of m* cars	Entering total times	Exiting total times
10	155	145
30	435	465
50	675	825
70	875	1225
90	1035	1665
110	1274	2442
130	1572	2968
150	1830	3538
170	2048	4148
190	2227	4915
210	2495	6435
230	2811	7706
250	3087	8723

Ⅸ. EXPERIMENT 3

Using the entering method type 1 and the exiting method type 1, calculate the total time of entering and exiting for each case when the number of cars M* is increased to 260, 280, ...,500. However, it is assumed that the stack can be generated on the m_2-1st floor.

A. Result

The flowchart of Experiment 3 is omitted because "FOR M*=10 TO 250 STEP 20" in the flowchart of Experiment 1 in Fig.18 was changed to "FOR M*=260 TO 500 STEP 20." Table 3 shows the total time of entering and exiting for M* cars.

Ⅹ. EXPERIMENT 4

Using the entering method Type 2 and the exiting method Type 2, calculate the total entering time and total exiting time for each case when the number of cars M* is increased to 260, 280, ..., 500. However, it is assumed that the stack can be generated on the floor directly above the top floor where the cell pallets are parked.

A. Result

The flowchart for Experiment 4 is omitted because it simply changes "FOR M*=10 TO 250 STEP 20" in two places in the flowchart for Experiment 2 in Fig.20 to "FOR M*=260 TO 500 STEP 20." Table 4 shows the total time of entering and exiting for M* cars.

Table 3. Total time of entering and exiting for M* cars in Experiment 3

Number of m* cars	Entering total times	Exiting total times
260	17482	55006
280	18783	59173
300	20034	63302
320	21582	67748
340	22748	71804
360	24244	76168
380	25662	80480
400	27147	84823
420	28511	89073
440	29729	93173
460	31076	97400
480	32657	101827
500	33852	105872

Table 4 Total time entering and exiting for M* cars in Experiment 4

Number of m* cars	Entering total times	Exiting total times
260	3210	9118
280	3426	10408
300	3636	13245
320	3990	13920
340	4304	17373
360	4578	17767
380	4812	19755
400	5052	23799
420	5424	29544
440	5756	29824
460	6048	32334
480	6300	36164
500	6570	40503

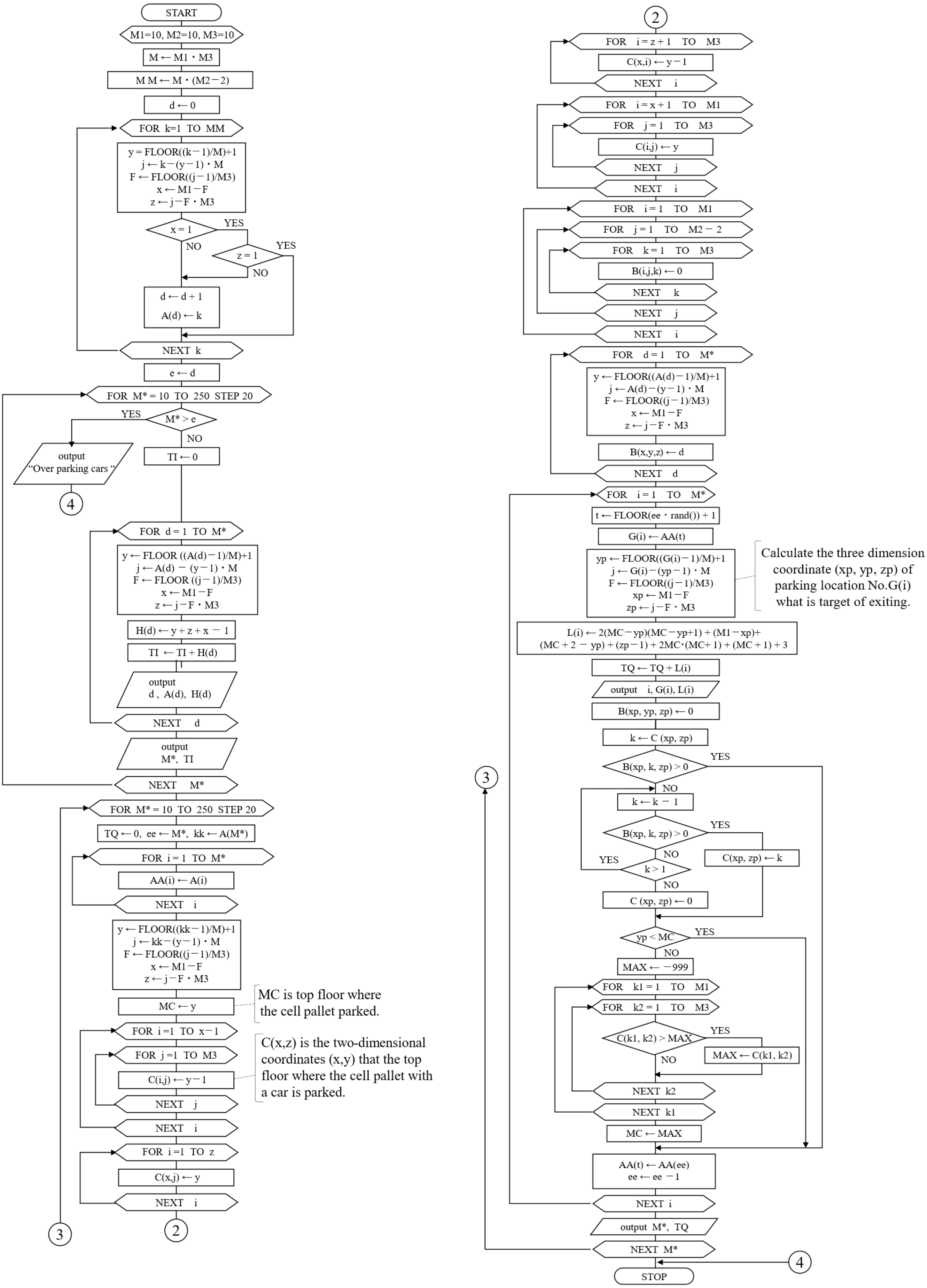


Figure 20 Flow chart of the Experiment 2

XI. CONCLUSION

We proposed an auto valet parking system that makes maximum use of three-dimensional space. We demonstrated auto valet parking by proposing an entering algorithm and an exiting algorithm using [13] for the target multi-story parking lot. In addition, experiments revealed that the proposed entering algorithm and exiting algorithm are time-efficient. Normally, with auto valet parking, customers get off at the entrance of the parking lot, so customers do not care about the time efficiency of entering cars, but parking lot managers are concerned about labor costs, electricity costs, etc.. Therefore, the time efficiency of entering cars is very important. In fact, where the car is parked greatly affects not only the efficiency of entering, but also the time efficiency of exiting the parking lot.

The advantage of the proposed entering method is that the order in which parking locations are determined is regular, and priority is given to locations as close to the exit as possible. And the difference between the values of each C(x,z) is only 1. However, C(x,z) represents the height y of the coordinates (x,y,z), and the possible difference in y is 1. In addition, this method reduces the number of floors used and contributes to lowering the cost of moving cell pallets entering and exiting. The advantage of the proposed exiting method is that the floor directly above the top floor (y floor) where the cell pallet is parked (floor y+1) and the floor above it (floor y+2) are used as passage area for the cell pallet The smaller y+2 is than m_2 (height of the parking lot), the better the time efficiency of exiting the parking lot.. In addition, the proposed parking lot [13] is a mechanical multi-story parking lot, and the height of each floor is approximately 1/2 the height of a mobile type parking lot, so it can arranged a large number of parking spaces. Accordingly, we experimented in a 10-story parking garage.

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