Proposal for automated valet parking to reduce exit time

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Abstract

An automated valet parking system that makes maximum use of three-dimensional space has been proposed due to a lack of parking spaces in major cities. This parking lot aims to maximize the number of parking and minimize entry and exit times. Therefore, there are no passages in the parking lot, and cars must move through the parking spaces to park to the desired parking location. Furthermore, cars are not driven by a driver, but are transported on self-driving rectangular pallets called cell pallets, which are large enough to fit one car. The parking lot is made up of a skeleton of poles like a jungle gym in a park, within which the cell pallets can move left and right and up and down on odd-numbered floors, and front and back and up and down on even-numbered floors. In this study, we present an improvement plan for the method of moving around in a parking lot, which is proposed as supporting research for the construction of a new moving system for the multi-story car parking lot. The aim is to verify this through simulation experiments and to improve the efficiency of the time it takes to enter and exit.

Key words
multi-story car parking, cell pallet, auto valet parking, improved entry and exit time, simulation experiments

1. Introduction

In recent years, research has been conducted into the future of multi-story parking lots in conjunction with the shift to self-driving cars, with auto valet parking (Kitagawa, 2021) attracting particular attention. It is a parking lot where cars enter and exit automatically. In addition to a paper published by the authors, there is another paper on auto valet parking (Yamamoto et al., 2023). In this paper, the entire parking lot is divided into a spatiotemporal grid, and a system is proposed that avoids collisions and congestion by reserving routes to reach the destination. However, this is not applicable to all cars. The main reason for this is that customers' cars are all different (they are diverse and have different performance, shapes, sizes, etc.), so universal control is not possible. In contrast, the auto valet parking system proposed by the authors is a system that allows any car to use the parking lot by introducing a method for transporting automobiles called a cell pallet. Additionally, parking issues are an important issue in the national policy of Smart City Initiative (NEC, 2022). As multi-story car parkings grow in size, issues such as accidents (traffic accidents, theft, etc.), the difficulty of finding a parking space, narrow getting on and off areas, and difficulty of use for beginners and seniors have become increasingly problematic. To solve these problems, an auto valet parking system using a unique automated pallet is proposed by the authors (Funase et al., 2022a). A method for determining parking locations with efficient exit time was also proposed (Funase et al., 2022b). In addition, the movement method of an automated pallet to improve exit time efficiency was proposed (Funase et al., 2023a), and the extent to which this could improve exit time efficiency was clarified through simulation (Funase et al., 2023b). The structure of the multi-story car parking lot targeted in this study is a parking lot that makes maximum use of three-dimensional space, as proposed in Funase et al. (2022c). In addition, Funase et al. (2024) was the first to present the basic entry and exit algorithm for this multi-story parking lot. Subsequently, Okada et al. (2024a) which is an improved version of Funase et al. (2024), was proposed. The multi-story parking lots covered in these references (Funase et al., 2022a; 2022b; 2022c; 2023a; 2023b; 2024; Okada et al., 2024a) are mechanical parking lots equipped with one elevator for entry and one for exit. Furthermore, Okada et al. (2024b) investigated three studies to speed up automated valet parking. The background to the growing demand for auto valet parking are expectations of improving the efficiency of parking lots in urban areas and enhancing convenience for users. Conventional parking systems are designed based on the simple allocation of parking spaces, so efficient car management and prompt exit response are issues to be resolved. A new system is required to optimize parking space allocation to solve these issues.

2. The target multi-story car parking

The target multi-story car park (Funase et al., 2022c) is composed of a jungle gym-like skeleton of poles, cell pallets (Funase et al., 2022c) that carry customers' cars move left and right, up and down, and back and forward. The entrance to the parking is located next to the leftmost parking space on the 1st floor of the front row, and the exit is next to the rightmost parking space on the 1st floor of the front row. Drivers are checked in at the entrance to the car parking lot, and are given a magnetic card with an ID number printed on it. In addition, a camera is installed at the entrance, which reads the customer's car license number plate and the driver's facial image, and these are then entered into a database along with the date and time of entry and the ID number. Then, the customer's car is placed on a cell pallet and moved to the coordinates (1, 1, 1), and a parking location number indicating the parking location is associated with the ID number. The entry algorithm is the cell pallet that carries the customer's car from coordinates (1, 1, 1) to the parking location (coordinates (x, y, z)). Parking location No. is a serial number assigned to each parking location from the 1st floor to the top floor, and the parking location No. on the floor which is directly above parking location No. j is m_1 m_3 + j. For example, in the case of the 1st floor, parking location numbers are assigned as shown in Figure 1. However, in the leftmost column, in order to make it a path for the cell palette, parking is not allowed in the parking location with coordinates (1, i, 1) (i = 1, 2, . . ., m_2). Additionally, m1 is the number of parking spaces per line and m_2 is the number of floors on the top floor. And m3 is the number of parking spaces per row. The m2 floor and m_2 – 1 floor are used as passageways for the cell pallets and for evacuation. To exit the parking, customers go directly to the exit and complete the exit procedure by entering the magnetic card on which the ID number is printed. Specifically, customers' cars are managed by the string on license number plates. For each string in the license number plate, the entry date and time, requested exit time, exit date and time for the customer's car are entered into the database, the parking location number is calculated from the ID number, and the cell pallet parked at the corresponding coordinates is moved to the coordinates (m_1, 1, 1).

3. Improved entry and exit time reduction and movement algorithm

Generally, mechanical multi-story parking lots, known as a puzzle-type parking lot, have parking spaces arranged in two columns x X rows or in a circle. However, when a large amount of parking is required in a relatively large space, such

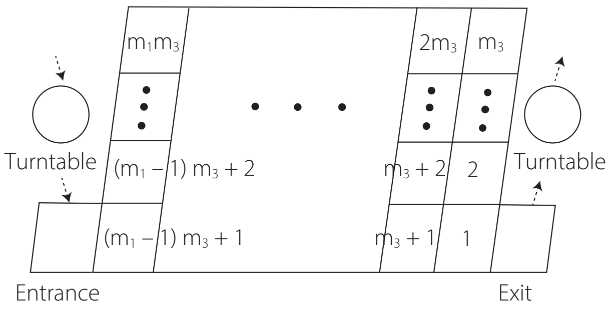

Figure 1: Parking location No. in 1st floor
Source: Funase et al. (2024).

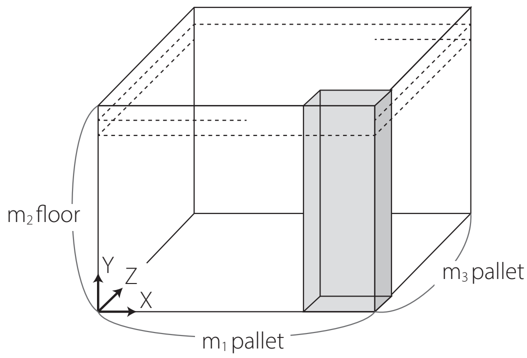

Figure 2: Spaces that are left empty without parking

as a large suburban shopping mall, event venue, theme park, or airport, it is necessary to increase the amount of parking space in a depth direction, and an efficient method of entering and exiting the parking lot is required. The parking lot that is the subject of this study can be one of the parking lots that allows efficient entering and exiting when the flat parking space is large, with three columns and three rows or more. As mentioned in the introduction, efficient entering and exiting algorithms for this parking lot have been discussed. Here, a method that can further reduce the entering or exiting time is proposed. The method focuses on the operational aspects of parking lots. This method leaves the parking space at coordinates (m_1, t, 1) (t = 1, 2, . . ., ω) (ω is the top floor where the cell pallet is parked) empty without allowing any cars to park there. An outline of this is shown in Figure 2.

The entering and exiting algorithm is changed as follows. The entering algorithm uses the method in Section IV of the paper by Funase et al. (2024). That is, the parking location for entry is determined in ascending order of the parking location number of the available parking space. In this study, the car is not allowed to park in the parking space with coordinates (m_1, t, 1) (t = 1, 2, . . ., ω). If the coordinates of the parking location of the cell pallet containing the car that has requested to be exited are (x*, y*, z*), the exiting algorithm first evacuates the cell pallet parked at the coordinates (x*, t, z*) (t = y* + 1, y* + 2, . . ., ω) (ω is the top floor where the cell pallet is parked) to the ω + 1 floor. Next, move the cell palette parked at coordinates (x*, y*, z*) to coordinates (x*, m_2, z*). Then, the evacuated cell pallet returns to its original position. Next, the cell pallet (coordinates (x*, m_2, z*)) containing the car that has been requested to be exited is moved to coordinates (m_1, 1, 1) and exited. In this study, the coordinates (m_1, t, 1) (t = 1, 2, . . ., ω) are left empty, so there is no need to evacuate the car.

4. Simulation experiments

4.1 Experimental conditions

Assume the target multi-story parking lot 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 (9th floor) are used as an aisle for moving cell pallets and a stack for temporary evacuation. Find the total exit time when the number of cars is increased to 10, 30, . . ., 250. However, assume the time taken for one unit of movement of the cell palette left and right, up and down, and forward and backward is all the same. In addition, the movement in this simulation is sequence controlled.

4.2 Experimental results

The experimental results are shown in Table 1. As shown in Figure 3, the entry time remained almost unchanged, but the exit time was reduced after the improvement. Also, when it comes to exits, the more cars there are, the more reduction time it takes to exit. The reduced time is especially significant when the number of cars increases from 90 to 110 and from 190 to 210.

4.3 Consideration of the experimental results

The reason why there was almost no change in the entry time is because cars are parked in order of lowest parking location number, and there is no need to remove them from the stack. In other words, the conventional program is already considered to be efficient. The reason for the slight time reduction is due to the fact that the spaces farther from the entrance have been designated as non-parking spaces, reducing the moving distance. When exiting, the cell pallet is exited from coordinate (m_1, 1, 1). Therefore, the cell pallets parked at (m_1, y, 1), (m_1, y − 1, 1), (m_1, y − 2, 1), . . . (m_1, 1, 1) must be temporarily removed to the stack on the y + 1 floor, which is closer to coordinate (m_1, y, 1). y is the top floor where the car is parked. Therefore, it is considered that the exit time was reduced by not parking at (m_1, i, 1) (i = 1, 2, . . ., 10). Also,

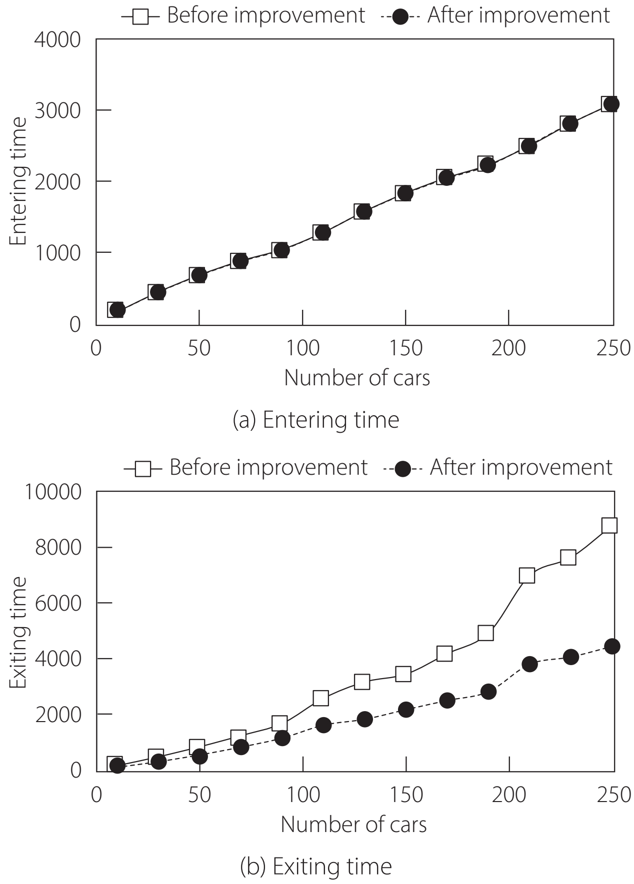

Figure 3: Comparison of simulation experiment results before and after improvement

when the number of cars increases from 90 to 110, or from 190 to 210, the number of floors for parking cars increases by one. And the number of floors for stacking and moving also increases by one. Therefore, it is considered that the exit time increases sharply because the amount of movement by one

Table 1: Result of simulation experiment

Number of cars	Entering		Exiting	
	Before improvement	After improvement	Before improvement	After improvement
10	155	154	145	86
30	435	432	465	288
50	675	670	825	530
70	875	868	1225	812
90	1035	1027	1665	1135
110	1274	1276	2570	1600
130	1572	1570	3156	1812
150	1830	1824	3438	2158
170	2048	2038	4172	2488
190	2227	2215	4915	2805
210	2495	2504	6984	3793
230	2811	2814	7632	4052
250	3087	3084	8783	4434

floor increases for all cars exiting.

5. Conclusion

The improvement method used showed that there was no difference in the entering time before and after the improvement, but it was shown that there was a significant reduction in the exiting time. We believe this effect is useful in situations where there is congestion when exiting a parking lot. Therefore, this will have a significant effect in situations where users return home at similar times, such as concert venues, exam venues, and theme parks, and will help solve the problem of congestion in multi-story parking lots. Furthermore, the more cars there are at the exit, the more time it saves, so this is considered preferable for large parking lots.

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