Study on Automated Valet Parking System using Multi-row Parking Berth with Circuit Path

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Abstract
In this study, using a parking lot of a large-scale commercial facility in the suburbs of Tokyo as a case study, we identified challenges in the parking lot and the value that can be created by using an automated valet parking system. The proposed Automated Valet Parking System using Multi-row Parking Berth with Circuit Path is characterized by the fact that the distance traveled by vehicles around the parking zone, the time required to exit the parking zone, and the efficiency of land use vary depending on the combination of the number of rows in the multi-row parking berths layout. Therefore, an evaluation of the 48-berth parking zone is conducted using actual parking demand data. As a result, the layouts with 4-row and 3-row are suitable from the viewpoint of shortening the time required to exit the parking zone after the start of exiting behavior, and the layouts with 2-row or 3-row are advantageous in terms of controlling the travel distance for relocation due to the installation of a circuit path. Besides, the result shows that the layout with a 6-row is about 21% more efficient and the layout with a 3-row is about 15% more efficient, compared with conventional parking zone layout in terms of required area.

Keywords Automated driving, Automated Valet Parking System, Social Implementation, Parking Layout, Simulation

1 Introduction

In recent years, automated driving technology has been moving from the research and development stage to the social implementation stage in many parts of the world. Although the levels of driving automation, use cases, and Operational Design Domain are diverse, most of them remain at the level 2 or lower of so-called SAE driving automation [1] to support safe driving. In addition, to reach the stage of full-scale deployment, several issues must be overcome not only in terms of technology but also in terms of business sustainability and social acceptance [2].

One of the use cases of automated driving that is expected to be widely implemented in society at an early stage is the Auto Valet Parking System (AVPS), which realizes automated driving in a parking lot [3][4].

AVPS automates the driver's operation in a parking lot. Three types of AVPS have already been classified under ISO 23374-1 [5]. A legal framework has been established and services have been launched in Germany [6], and other efforts toward social implementation are underway.

However, actual implementation examples are limited, and AVPS, like other use cases, has not yet reached the stage of full-scale diffusion and deployment. One of the reasons for this is the diversity of options for the division of functions and roles between the vehicle side and the parking infrastructure side in the implementation of AVPS, as well as the diversity of stakeholders, including vehicle OEMs, parking equipment manufacturers, parking facility owners, and parking facility users. In other words, the lack of a social implementation scenario that clarifies the value to be realized in AVPS and minimizes the additional investment for each of the various stakeholders is hindering its widespread deployment [7].

To resolve the above issues for the broad social implementation and deployment of AVPS, this study first clarifies the values of AVPS based on the views of various stakeholders. Next, we propose AVPS using a Multi-row Parking Berth with Circuit path (AVPS-MPBC) as a simple AVPS for use with SAE Level 2 automated vehicles, which are already commercially available. We define the necessary vehicle functions and parking infrastructure functions, including the parking zone layout. To verify the effect of the number of stacking rows of parking berths used in the AVPS-MPBC, we quantitatively evaluate the time required for vehicles to exit, the distance traveled in the parking zone, and the land use efficiency. The evaluation is not based on stochastic numerical experiments, as in previous studies, but on actual parking data such as vehicle arrival and stay times at large suburban commercial facilities.

2 Previous studies and experiments

2.1 Studies on AVPS

There are several previous studies on the design and optimization of parking lot layouts for automated vehicles. Among them are efforts to minimize the rearrangement of parking spaces when vehicles with blocked fronts exit by devising a parking position selection algorithm while increasing land use efficiency by allowing parking in multiple rows as in valet parking services [8], and to study parking zone layouts to minimize relocations [9].

These studies do not consider the feasibility for social implementation of automated vehicle relocation. That is, they assume that automated vehicles can move to any location for relocation without considering the interaction between vehicles, without even considering the level of commercially available automated driving technology. In addition, the evaluation did not sufficiently consider the actual arrival and departure times of individual vehicles at parking lots, which vary depending on the time of day.

Similar previous studies in other fields have dealt with the container relocation problem in container storage yards [10][11] and the shunting problem in bus/tram depots [12][13]. However, the AVPS-MPBC addressed in this study differs from the container relocation problem in that the direction of movement and repositioning is unilateral, forward only, unlike containers that are always moved backward for repositioning only from the top. Also, in AVPS-MPBC, arrival and departure times are stochastic, unlike trams and buses, where arrival and departure times are deterministic based on a pre-planned schedule.

2.2 Experiments of AVPS

There are several examples of demonstration experiments for social implementation of AVPS. For example, in Japan, the Japan Automobile Research Institute (JARI) conducted a case study in a self-propelled parking lot in November 2018 as a project of the Ministry of Economy, Trade and Industry. Features of the system include driving in an area dedicated to AVPS, using vehicles from four different automakers, laying landmarks for self-positioning correction, and recognizing obstacles and parking slots around the vehicle using existing sensors such as onboard cameras and sonars [14]. A demonstration experiment was also conducted at the Keihanna Open Innovation Center in February 2021 [15]. These are characterized by the fact that AVPS is realized in a mixed environment with ordinary vehicles, and there are issues in that value creation with the use of automated vehicles, which will be discussed later, is insufficient.

As an example of social implementation, the commercial service using AVPS has launched at the Stuttgart Airport, only for some high-end vehicles of specific manufacturers, installing in the parking infrastructure with LiDAR (Light Detection and Ranging) sensors after approval by the Federal Motor Transport Authority (KBA: The Kraftfahrt-Bundesamt) in November 2022 [6].

Some OEMs have already released high-end vehicles to the market that are equipped with a function that allows the vehicle to drive from the starting point to the ending point according to the stored route by setting the route traveled once and the location of the parking space [16], and to park and retrieve the vehicle automatically while standing outside the vehicle [17]. However, these are implemented as part of the vehicle's stand-alone driver assistance function and are not an initiative aimed at improving the efficiency of parking.

2.3 Features of this study

The features of this study that distinguish it from previous studies and efforts are as follows. First, this study is different from previous studies in that it identifies issues in existing parking facilities with stakeholders, constructs a hypothesis of value creation by automated valet parking technology, and clarifies the value of AVPS, the division of functions based on this value, and the necessary investment associated with this value creation.

Second, we propose the AVPS-MPBC as a cooperative AVPS that can be widely used not only in high-end vehicles but also in vehicles equipped with automated driving functions of a technological level that is widely available in the market.

Third, the evaluation of AVPS-MPBC is conducted using actual data of vehicles using parking lots that reflect the characteristics of individual vehicles.

3 Issues in existing parking lots

3.1 Identification of issues in existing parking lots

To clarify the social implementation scenario of AVPS this study adopted the approach of clarifying the issues of existing parking lots that can be addressed by AVPS, before defining each role and function requirement of the vehicle and parking infrastructure. Specifically, we first visited a large-scale commercial facility with 7,300 parking berths in a suburban area of Tokyo in September 2022 with 16 members of the special research committee on parking ITS as shown in Table 1.

Table 1. Members of the research committee on parking ITS

Organization of members
- Automotive OEM
- Tier 1 supplier
- Sensor device manufacturers
- Commercial property developer
- Academia

In discussions with stakeholders, including parking lot owners, it was found that the issues shown in Table 2 must be overcome, especially in current large-scale parking facilities.

First is the prevention of accidents in parking lots. When an accident occurs in a parking lot, the parking lot management needs to take various actions by its staff. In addition, the cost of installing camera monitoring systems in the parking lot for early response has been incurred, and there is a need to reduce these cost.

Second, the time that users spend wandering around the parking lot looking for a parking berth and the time they spend walking from the parking berth to the entrance/exit of commercial facilities reduce the time they spend at the

Table 2. Challenges in parking lots

Challenges extracted by study group members
- Accidents and thefts in parking lot
- Prowling for empty parking berth
- Walking from the parking berth to the entrance and carrying goods from the exit of the facility
- Goods cart collection
- Decrease in facility area due to securing parking zone area
- Avoidance of narrow parking berths by elderly and other drivers with poor parking skils
- Securing special parking berths for the physically challenged and elderly
- Long exit times during congestion in the parking lot
- Provide services for parked vehicles (car wash, charging, etc.)

commercial facilities, which are their original destinations, and there is a need to increase the time users spend at the facilities from the perspective of sales.

Third, while the facility side should have a parking lot that can accommodate as many users as possible in as small an area as possible, in recent years, due to the diversification of drivers, including the aging population, there is a need to respond to the preference to parking lots with parking berths that are larger in size and with more space between them, otherwise, the motivation to visit a facility will decrease. A well-balanced response to these conflicting issues is required.

3.2 Expected values to be created by AVPS

Based on the results of 3.1, we clarified the values that can be created by solving problems by introducing AVPS, along with the conditions necessary to solve them. Then, we categorized the entities that would be primarily affected by these values. The results are shown in Table 3.

As shown in Table 3, much of the value that can be created by AVPS benefits not only users but also facility developers. In other words, it is desirable for both the vehicle side and the parking infrastructure side to share roles and costs in social implementation, and a cooperative approach is essential.

Table 3. AVPS Solution and Value Created

<Solution 1>			
Separate the parking zone from the drop-off and pick-up zones to be located near the entrance and exit of the facility, and make the parking zone unmanned.			
<Value Created>	User	P.D.	Public
Allows users to get in and out near the entrance/exit of the facility. Eliminate walking in the parking zone.	○		
Users can stay longer at the facility.	○	○	
Accidents and thefts can be eliminated.	○	○	○
No need to deploy guidance staff and monitoring equipment to prevent accidents.		○	
More flexibility in the layout of the parking and facility zones.		○	
The need to collect the goods carts is eliminated.		○	
<Solution 2>			
Use AVPS to move vehicles in the parking zone.			
<Value Created>	User	P.D.	Public
Eliminating prowling trips to find empty parking berths can increase the time spent at a facility and reduce energy consumption.	○		○
Moving vehicles to the near exit point to reduces the time required to exit the parking zone.	○		
Users stay longer at the facility, which increases the facility's revenue.		○	
Parking maneuvers can be eliminated.	○		
The number of parking berths per area can be increased by eliminating the need to open doors and by allowing repositioning.		○	

P.D. : Property Developer

4 AVPS-MPBC

4.1 Conditions

In creating value through AVPS as clarified in 3.2, the following conditions must be met.

First, from the perspective of preventing accidents in the parking lot and maximizing the time users spend in the facility, the drop-off/pick-up zones located near the entrance and exit of the facility should be separated from the parking zone, and the parking zone should be unmanned. This will eliminate accidents between pedestrians and vehicles in the parking lot, decrease the walking time between vehicles and facility entrances/exits, and increase the time users spend in the facility. In addition, it will be possible to drive at low and uniform speeds around 4-5 km/h in the parking zone, enabling safe automated driving within the parking zone even with vehicles of current commercial technology levels.

Second, from the aspect of improving the land-use efficiency of the parking zone, it is necessary to make the parking berths a multi-row layout, as proposed in previous studies [8][9]. Unmanned parking zones using AVPS can reduce the lateral room for door opening and closing. In addition, by taking advantage of automatic operation to move and re-park vehicles during parking time, similar to so-called valet parking, it is possible to increase the number of longitudinal rows, beyond conventional two rows, so that an area equivalent to decreased driving path can be allocated to parking berths, thereby improving the land use efficiency. However, in actual parking lot use, the time of parking lot use differs for each user, and depending on the heterogeneity of parking lot demand, the operation of moving and re-parking becomes complicated and cannot be easily handled with the technology level of vehicles already on the market. For social implementation, it is necessary to make it possible to move and re-park with simple movements even for realistic non-uniform arrival and departure parking demand, and for this purpose, it is effective to install a circuit path as shown in Figure 1. The only function required of the vehicle is an automatic operation function that moves forward, turns right, turns left, or stops at a certain speed based on information from the parking infrastructure, and this function can be implemented with the technology level of vehicles already available on the market.

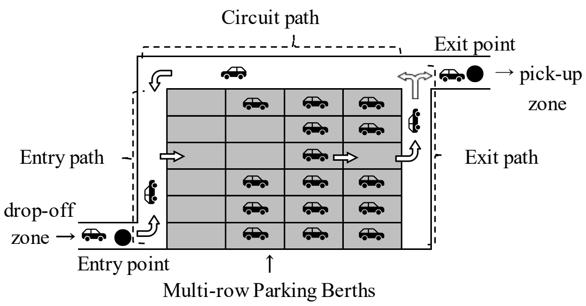


Figure 1. Layout of parking zone for AVPS-MPBC

To meet these requirements, the AVPS-MPBS must have the functions shown in Table 4.

Table 4. AVPS-MPBC function

Functions of parking infrastructure
<drop-off/pick-up zone>
- Accessible vehicle screening function
- Guidance function from the drop-off point to the entrance of the parking zone
- Exit request receiving function
- Guidance function from parking zone exit to pick-up point
<parking zone>
- Vehicle location monitoring function
- Vehicle behavior decision-making function
- Behavior information communication function
<others>
- Parking fee collection function
- Exit time registration function
- Wireless power transfer function
Functions of vehicle
- Behavior information communication function
- Autonomous driving function (market level)

On the parking infrastructure side, the AVPS needs two main functions: vehicle guidance in the drop-off and pick-up zone and vehicle guidance in the parking zone. In the parking zone, the functions of monitoring where each vehicle is located in the parking zone, determining the behavior information of "forward," "right turn," "left turn," and "stop," for guiding incoming vehicles to the parking position closest to the exit path, guiding outgoing vehicles to the exit path, and guiding forward-parked vehicles to drive around via circuit path and re-park in the parking zone. In addition, a function to provide the behavior information to the vehicle is required.

From the viewpoint of user convenience, a function for registering and changing the scheduled departure time using a smartphone application, etc., and a function for non-contact wireless power supply to vehicles within the parking zone are also expected.

On the vehicle side, only a function to receive behavior information generated by the parking infrastructure and a function to "move forward," "turn right," "turn left," or "stop" at a uniform low speed using the automated driving function of the vehicle based on behavior information are required.

4.2 Features and Challenges of AVPS-MPBC

In previous studies that have proposed multi-row parking berth layouts for automated vehicles, the approach taken is to use empty parking berths and driving paths to perform autonomous forward/backward and left/right movements on the vehicle side to re-park at designated positions [8][9]. On the other hand, in this study, each vehicle is always guided and moved to a position as close as possible to the exit path, thereby reducing the time required to exit the parking zone while maintaining multiple rows of stacking vehicles. In addition, by providing a circuit path, when a vehicle with a short parking time is parked behind a vehicle with a long parking time, the vehicle parked in front is guided to the circuit path and re-parked. In this way, only forward movement is required within a parking zone. This minimizes the number of vehicle interactions within the parking zone, and the system is characterized that it achieves relocations based on the automatic driving function of the vehicle side. Therefore, the proposed system can improve land use efficiency as a multi-row parking berths layout even if the parking time of individual vehicles is not known in advance. The feature of this AVPS is that the distance traveled by vehicles, the time required for exit, land use efficiency, etc. vary depending on the layout of the parking zone, that is, combination of the number of rows and lanes of parking berths. For example, even with the same number of parking berths, the number of vehicles that need to make a relocation trip during parking differs greatly between a layout with N lanes by 1 row and a layout with 1 lane by N rows, and the land use efficiency also differs because the length of the circuit path is also different. Therefore, it is important to design an appropriate layout of parking berths, i.e., the number of rows and lanes of parking berths, according to the characteristics of vehicles using the parking lot.

5 Comparative evaluation of different layouts

5.1 Data used in the evaluation

As described in 4.2, the AVPS-MPBC proposed in this study has a feature that its performance varies significantly depending on the design of the parking berths layout. Therefore, in this study, we evaluate the performance change due to differences in parking berths layouts using actual parking lot demand data of a large-scale commercial facility. The evaluation is performed only for the parking zone excluding the drop-off/pick-up zone.

The data used for the evaluation is the November 2022 data of a parking lot in a large shopping mall in the suburbs of Tokyo. Figure 2 and Figure 3 show the number of parking vehicles by time zone for 30 days during the facility's operating hours, i.e., from 10:00 to 22:00, on weekdays, and weekends and holidays.

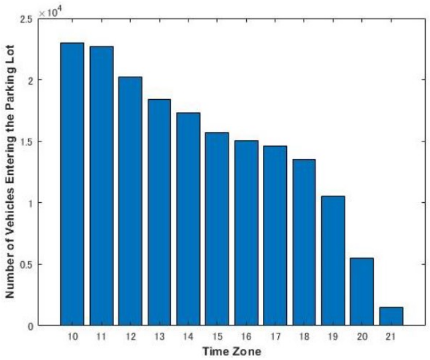


Figure 2. Number of Vehicles Entering the Parking on Weekdays

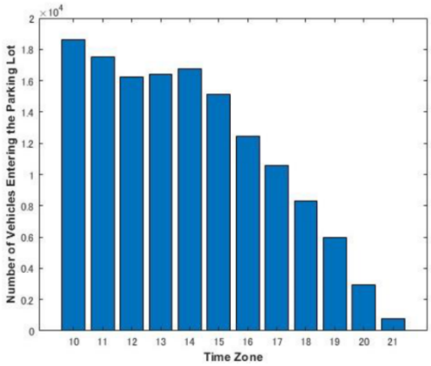


Figure 3. Number of Vehicles Entering the Parking on Weekends and Holidays

5.2 Methods

A cellular automaton model and multi-agent system are used for evaluation. The cellular automaton model, which can reproduce complex phenomena by using cells arranged in a uniform grid and assigning simple states to each cell, can simulate the phenomenon such as automobile traffic congestion and the arch phenomenon, in which people rush to a narrow exit and the exit is clogged. The AVPS-MPBC proposed in this study can also be applied to the cellular automaton model by configuring the enter path, circuit path, exit path, and parking berths with uniform cell, because the vehicles move at a constant uniformed speed to prevent accidents between vehicles in the parking zone.

A multi-agent system, in which multiple autonomous agents are deployed and model relatively complex events through interactions among the agents, can be applied to the study such as traffic congestion mitigation measures at intersections and modeling traffic accidents.

For evaluation of the AVPS-MPBC, a multi-agent system is useful in the situation where individual vehicles move through a parking area based on different arrival and departure times.

The evaluation environment is constructed using commercial numerical analysis software. In the simulation, square cells are arranged to simulate a parking zone, as shown in Figure 4, where the cells with black circles are the entrances and exits of the parking zone. The entrance and exit of the parking zone are only one each to simplify the layout of the parking zone. The cell size is defined as a square of 2.5m by 2.5m. The reason for this is that a typical parking space in Japan is 2.5m by 5.0m, so two cells can represent one parking square. Each parked vehicle is represented as an agent with the size of two cells. That is, for this evaluation, we assume that all vehicles' size are within two cells (2.5m by 5m).

Each agent moves within the parking zone according to the rules shown in Table 5 at each fixed time step. For the evaluation, one step is assumed to be 2 seconds, and each agent moves one cell per step. 2.5 m is assumed to be moved in 1 second, or at a speed of 4.5 km/h.

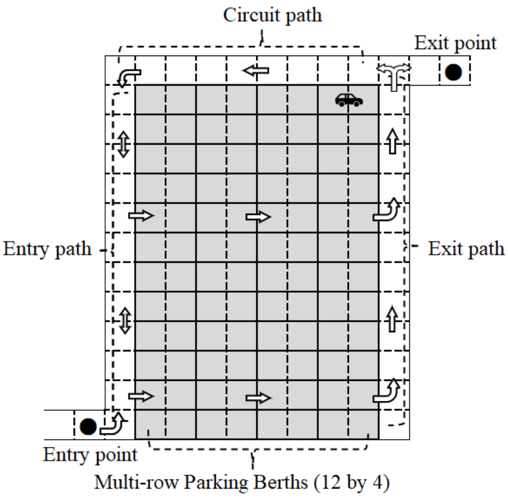


Figure 4. Basic cell layout for Evaluation

Table 5. Agent behavior rules

Rules
- If there is no agent at the entry point, an agent is generated in the entry point according to the entry probability for each step.
- If there is no agent in front cell nor in front of the right side cell, moves one cell per step. .
- Proceeds to the entry path from entry point if no other agent is present on entry path nor the end of circuit path.
- Stop at entry point if other agent is present on entry path or the end of circuit path.
- Proceed to the parking berth lane with the fewest number of agents at the time of entry.
- In the parking berths lane, move to the berth ahead as much as possible.
- At each step, an exit decision is made respectively according to the cumulative parking time function.
- The agent which exit decision made moves forward in the parking berths lane and exits through the exit point via the exit path.
- If there is any exiting agent behind in the same parking lane, the agent moves forward in the parking lane and moves to the end of the circuit path via the exit path.
- At the end of the circuit path, If there are no agents on the entry path, move to the parking berths lane with the fewest number of agents via entry path.
- Stop at the end of the circuit path, if there is other agent on the entry path.

This is consistent with the function identified as necessary on the vehicle side in the previous section, which is to move at a constant unified speed of 4 to 5 km/h. The evaluation time is 12 hours from 10:00 to 22:00, or 21,600 steps, which corresponds to the opening hours of the commercial facility.

The data presented in 5.1 are used to generate agents for each step. Specifically, the number of parked vehicles per hour is divided by the total number of vehicles that entered the parking lot between 10:00 and 22:00 to calculate the probability of entering the parking zone during each hour. Then, a random number between 0 and 1 is generated for each step, and a new agent is generated when the value of the random number is less than the entry probability for each hour. The data shown in Section 5.1 is also used to determine whether each vehicle leaves the parking lot at each step. Specifically, the cumulative parking time distribution function shown in Figure 5 and Figure 6 is calculated for each hour based on the actual parking time data for individual vehicle. If the value of the random number is less than the cumulative distribution probability for each agent's parking time, the agent starts to move out of the parking zone. For the layout of the parking berths to be evaluated, the total number of parked vehicles is set to 48 to increase the number of matrix combinations. The evaluation is performed in ten layouts: 1 by 48, 2 by 24, 3 by 16, 4 by 12, 6 by 8, 8 by 6, 12 by 4, 16 by 3, 24 by 2, and 48 by 1.

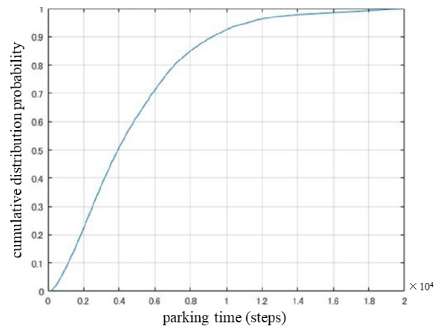


Figure 5. Cumulative parking time distribution function for Weekdays at 10:00

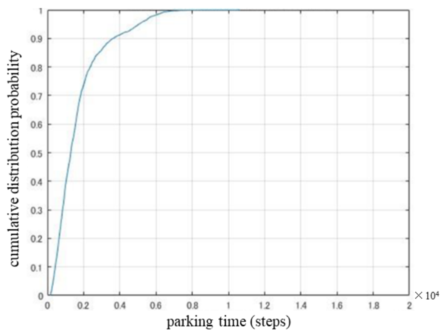


Figure 6. Cumulative parking time distribution function for Weekdays at 20:00

5.3 Evaluation indicators

Three indicators are used for comparative evaluation by layout. The first is the duration of time from the start of each agent's exit behavior until it arrives at the exit point. One of the objectives of the proposed AVPS-MPBC is to increase the time users spend in the facility. Therefore, we evaluate how the time required to exit the parking zone varies depending on the layout of the parking berths. The second is the distance traveled by each vehicle from the time it enters the parking zone to the time it begins exit behavior. In the proposed AVPS-MPBC, energy is consumed as vehicles repeatedly move around within the parking zone according to the parking berth layout and the heterogeneity of each vehicle's parking demand. Therefore, we evaluate how the travel distance due to the relocation movement changes according to different parking berth layouts. The third is the area required for the entire parking zone, including the paths.

5.4 Results

The time required to exit the parking zone is evaluated for each of the ten parking berth layouts. Figure 7 shows the results of the evaluation using weekends and holidays parking demand data. The results for the 6-row, 4-row, and 3-row layouts are relatively short, with an average time of about 22-24 seconds and a 75th percentile values of about 26-30 seconds. The 1-row and 2-row layouts, in which no or few trips for relocations are considered to occur, required more time due to the longer distance of the travel on exit path.

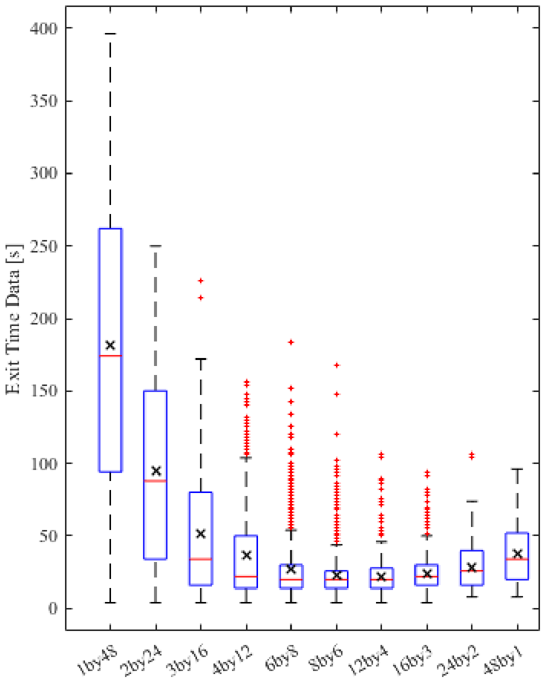


Figure 7. Time required to exit parking zone by layout

The distance traveled before the start of the exit behavior is evaluated for each parking zone layout. Figure 8 shows the results of the evaluation using parking demand data on weekends and holidays. In the layouts with 4-row, 3-row, and 2-row, the average values of distance traveled are about 45-51m, and the 75th percentile values are about 50-65m, which are shorter than in the other layouts.

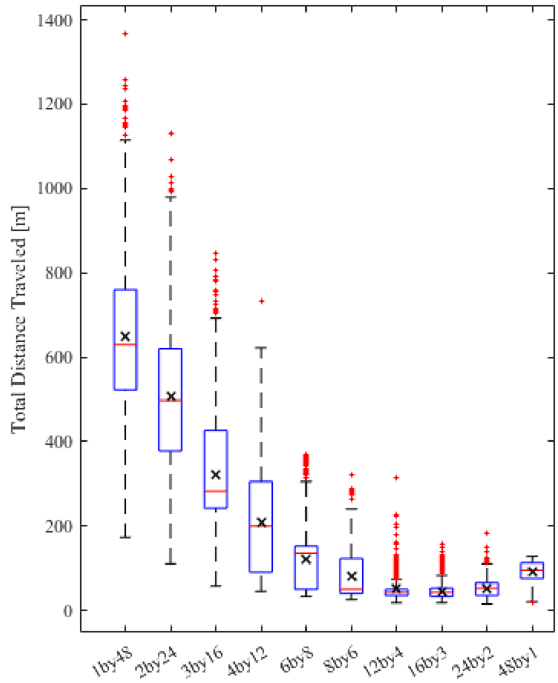


Figure 8. Distance traveled before exit behavior by layout

Figure 9 shows the results of evaluating the area required for the parking zone for each layout. The results show that the required area of the layouts with 8-row and 6-row, which are close to a square, are smaller than the other layouts. Comparing the 6-row parking lot with the smallest required area with the normal parking zone layout shown in Figure 10, the required areas are 812.5 m^2 and 1025 m^2, respectively, indicating an area reduction of about 21%, while the 4-row and 3-row layouts are effective in reducing the required area by about 18% and 15%, respectively.

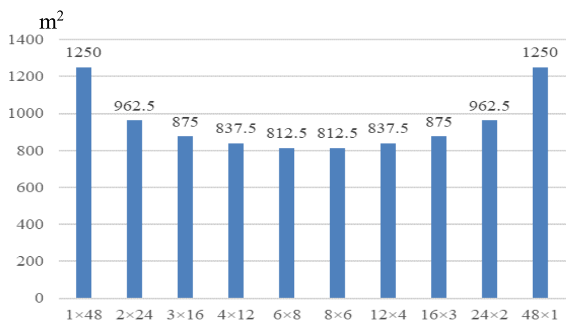
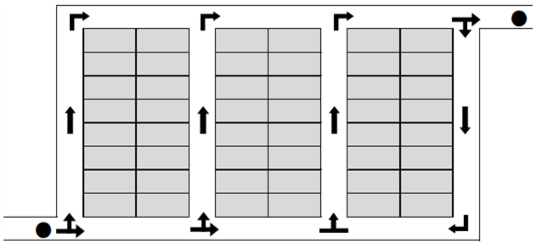


Figure 9. Area by parking zone layout



Area=1025m²

Figure 10. General parking layout for comparison

The results of quantitative evaluation using data that is in line with the actual parking demand of parking lots show that the AVPS-MPBC proposed in this study has the following features, according to the parking zone layout.

First, when the number of stacking parking rows is increased to three or more rows for the same number of parking berths, the average time required to exit up to eight rows is shorter than that for the layout with two rows. In other words, the AVPS-MPBC does not increase the waiting time for summoning the vehicle extremely long for these layouts. However, when there are six or more stacking rows, the maximum time required to exit the parking zone is substantially longer than when there are two rows, so 4-row or 3-row layouts are preferable.

Second, the results of the evaluation of the distance traveled during parking show that the average distance traveled is shorter for the 6-row, 4-row, 3-row, and 2-row layouts than for the 1-row layout, where no relocation movement is occur during parking. The maximum travel distance for a 2-row or 3-row layout is less than 1.5 times of the maximum travel distance for a 1-row layout, while the maximum travel distances for 4-row and 6-row layouts are about 2.5 times of the maximum travel distance for a 1-row layout. These results indicate that when the total number of parking berths is increased, the maximum distance of the circuit move for relocation may become non-negligible when a layout with four or more rows is adopted. It should be noted that the above results depend on the arrival and parking time distribution of parking vehicles.

Third, the required area for AVPS-MLBC, which requires a circuit path in addition to the area for parking berths and enter/exit path, can be reduced by about 21% in the case of 6- row and by 15% in the case of 3-row compared to the normal layout. In reality, the required area can be expected to be reduced by even more since this value does not include the point where doors do not need to be opened and closed, nor does it include facilities such as stairs and elevators that are needed for movement between the parking zone and the facility.

6 Conclusion

In this study, using a parking lot of a large-scale commercial facility in the suburbs of Tokyo as a case study, we identified parking issues and the values that can be created using AVPS. The AVPS-MPBC is featured in that the distance traveled by automated vehicles during parking, the time required to exit the parking zone, and the efficiency of land use vary depending on the combination of the number of stacking rows and parking lanes in the multi-row parking berths layout, so we evaluated the AVPS-MPBC using actual parking lot demand data such as arrival time and parking time distribution. As a result, for the parking demand data used in this evaluation, the layouts with 4-row and 3-row are suitable from the viewpoint of shortening the time required to exit the parking zone after the start of exit movement, and the layouts with 2-row or 3-row have the advantages in terms of controlling both average and maximum travel distance for relocation due to the installation of a circuit path. In addition, it is found that the required area can be improved by about 21% in the case of the 6-row layout, and by about 15% in the case of the 3-row layout.

The following issues need to be addressed in the future. In this study, the number of parking spaces is fixed at 48. It will be necessary to study the optimal number of exit points and the number of circuits when the number of parking berths is increased to the scale of 1,000, which is required in reality. In addition, it is necessary to study an operation method that can suppress the travel distance for relocation when the parking time of some vehicles are known. It is also necessary to verify on the ground using actual vehicles whether the AVPS-MPBC proposed in this study can be used with SAE Level 2 vehicles, which are already commercially available, and to what extent the size of the parking space can be reduced for social implementation. It is also necessary to study and verify the operation of the drop-off/pick-up zone, which is not addressed in this study.

7 Acknowledgments

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List of Abbreviations

AVPS: Auto Valet Parking System
AVPS-MPBC: Auto Valet Parking System using Multi-row Parking Berthe with Circuit Path
ISO: International Organization for Standardization
ITS: Intelligent Transport Systems
OEMs: Original Equipment Manufacturer
SAE: Society of Automotive Engineers

Statements and Declarations
Competing Interests:
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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