# Proposal of a multi-story car park with cell pallets to maximize space utilization efficiency in confined area

**Shinichi Funase, Toshihiko Shimauchi, Haruhiko Kimura, Hidetaka Nambo**

*Abstract*— **In many city centers, there is a chronic shortage of parking space and parking fees are very high since the land prices in these areas are extremely expensive and it is more cost effective to use a land as a rental building rather than to use as a car park. However, there are many companies that need to prepare parking spaces for customers and employees or sales-call vehicles even if they are expensive. This research proposes a multi-story car park that makes the best use of the three-dimensional space in a city center. The existing multi-story drive-in car park requires a space for movement and a space for elevating and lowering slopes to each floor in addition to the parking space. The mechanical car park requires expensive equipment with a complicated mechanism. The three-dimensional multi-story car park proposed in this paper is composed of pole skeletons like a jungle gym in a park, and movement to the parking space is performed by a cell pallet. The cell pallet has a floor area large enough to accommodate one vehicle, with a floor thickness of 20 to 30 cm that is sufficient to support the weight of the vehicle on it. 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.**

*Index Terms*— **Multi-story car park, mechanical multi-story car park, cell pallet, electric gear wheel, wheel stopper.**

## I. Introduction

A parking lot is a place for parking a car and can be roughly divided into a flat parking lot and a multi-story parking lot. 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. Both types are often introduced in large shopping centers in urban areas and suburbs. In addition, parking lots installed in the basement or rooftop of buildings or condominiums may also be defined as multi-story car parks. In many cases, there is no limit on the height of vehicles in flat parking lots, but most drive-in multi-story car park have height restrictions except for large-scale parking lots [1]–[6].

Some of the simple ones in urban areas are assembled from steel. The first underground parking lot in Japan is built in 1960 near Tokyo Station between the Marunouchi Building and the Shin-Marunouchi Building and has a capacity of about 500 cars [7].

A drive-in car park has multiple floors connected by slopes. The first example in Japan is the "Marunouchi Garage" in Tokyo, which opened in June 1929 (reinforced concrete 6-story building with 208 parking spaces. Dismantled in 1966).

For a mechanical car park, a driver does not have to drive in the garage; the driver gets off the car and the unoccupied car is automatically transported by mechanical systems installed in the car park. In 1929, Toshikichi Kaku from Osaka acquired a utility model for a tower-type parking lot, but he was not able to put the idea into practical use. The mechanical system has various models in terms of the number of stages and movement mechanism: multi-stage (39%), two-stage (25%), vertical circulation type (17%), and elevator type (10%) [8]. Compared to a drive-in car park, a mechanical car park has stricter restrictions on vehicle height (< 1550 mm) and width (< 1850 mm) Therefore, it may not be possible to park some types of cars such as tall cars (light trucks, some SUVs, tall wagons) or wide cars (luxury cars). When built on a small site, sometimes turntable is installed [9].

Each variety of multi-story car park 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 is a type of parking lot where cars are vertically stacked up in multiple stages [10]. 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 [11]. 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

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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 [12].

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.

The purpose of this research is to propose improvement of multi-story mechanical car park in terms of convenience and capacity. Specifically, we propose a system that combines a multi-story car park that is constructed like a jungle gym by combining poles and an electric cell pallet that moves both horizontally and vertically with a vehicle on it. The proposed car park possesses the advantages of the existing mechanical and self-propelled types with large capacity and high parking efficiency per floor area.

## II. Component of Proposed Parking System

### *A. 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 and right, front and back, and up and 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.

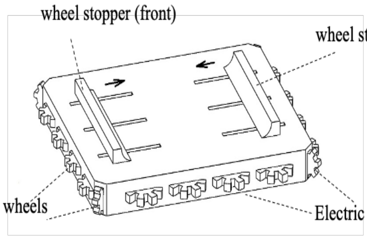

Fig.1 Cell pallet structure

### *B. Entrance operation*

The vehicle arriving at the parking entrance is parked at a designated place on the turntable where a cell pallet is embedded (Fig. 2). The driver gets off from the vehicle and receives a parking slip with a unique code printed on it. When the car is parked in the position where the cell pallet is embedded, the front and rear tire stoppers retracted in the pallet are deployed. The front and rear stoppers move in opposing direction to cramp the tires securely. After securing the vehicle, the cell pallet goes down to underground level where a pallet passage leads to the multi-story car park. After the pallet with the vehicle vacates the turntable, a new cell pallet is placed for a new vehicle to accommodate (Fig. 3). These operations are handled by the operator in the control room.

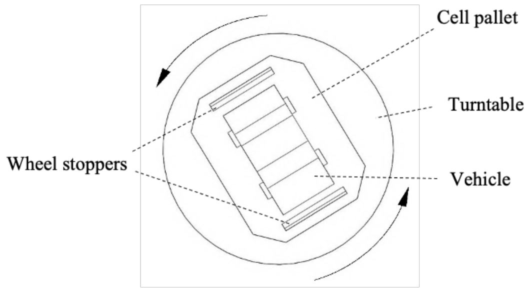

Fig.2 Turntable used for entrance and exit operations

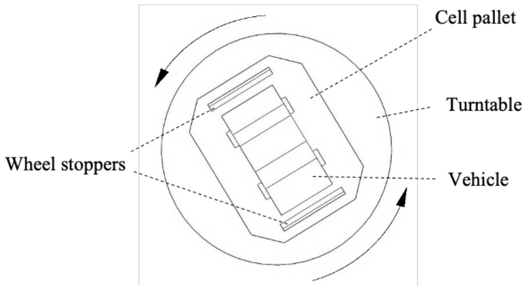

Fig.3 Schematic image of entrance operation

### *C. Operation of cell pallet*

The proposed multi-story car park consists of a pole skeleton (Fig. 4) like a jungle gym, in which the cell pallet moves both horizontally and vertically. The mechanism of each operation will be described below.

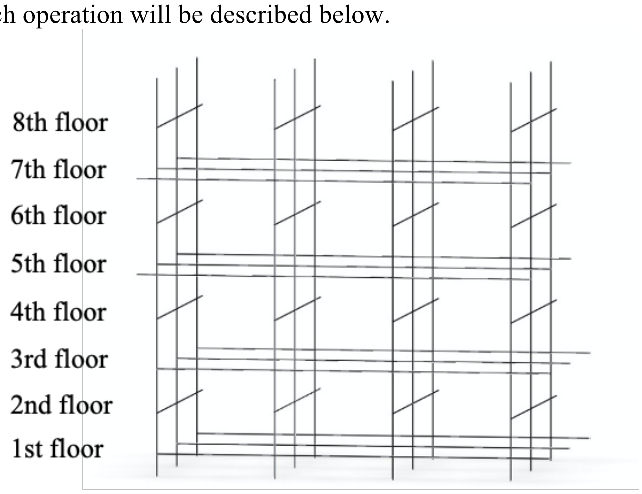

Fig.4 Skelton structure of proposed car park: each floor accommodates 6 vehicles.

1. longitudinal movement

Figure 5 shows a conceptual diagram of the longitudinal movement of the cell pallet. During the longitudinal movement, only the electric gear wheels on the long 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 longitudinal movements of the pallet. Figures 6 and 7 show the combination of the gear wheel and the gear rack in plan and side views respectively. Figure 8 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 longitudinal movement. By operating these steps for the four gear wheels on the side, the pallet can pass through the vertical pole.

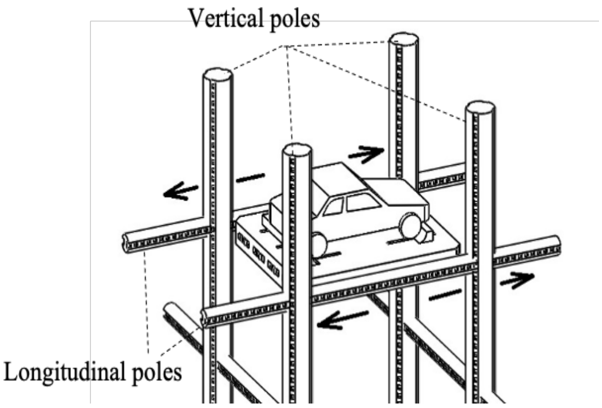


Fig.5 Schematic image of longitudinal movement

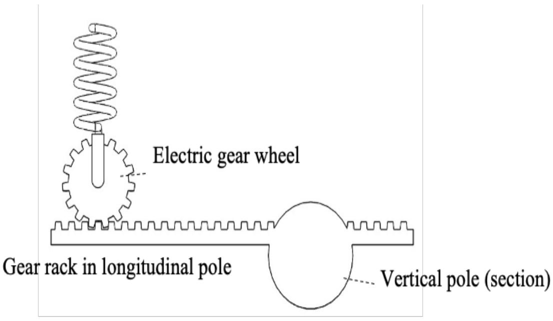


Fig.6 Electric gear and gear rack in longitudinal pole (plan view)

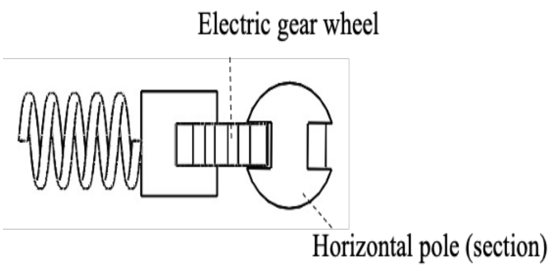


Fig.7 Electric gear and gear rack in longitudinal pole (side view)

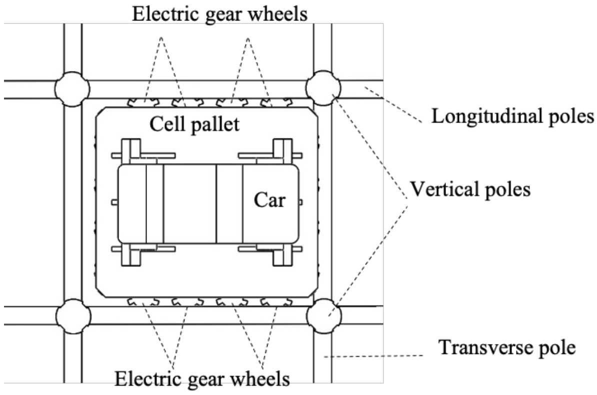


Fig.8 plan view of longitudinal movement

2. vertical movement

Figures 9 and 10 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 longitudinal movement, except for in the case of vertical movement, there exists no poles to hinder the movement. Figure 11 shows the cross-sectional structure of the vertical pole.

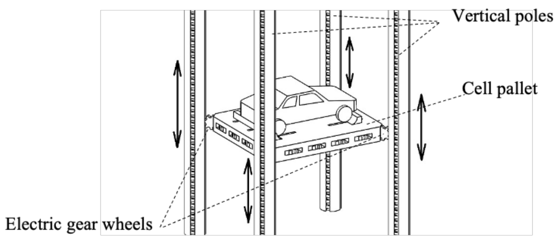


Fig.9 Schematic image of vertical movement

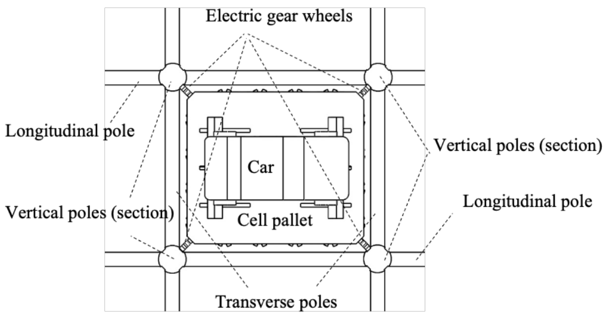


Fig.10 plan view of vertical movement

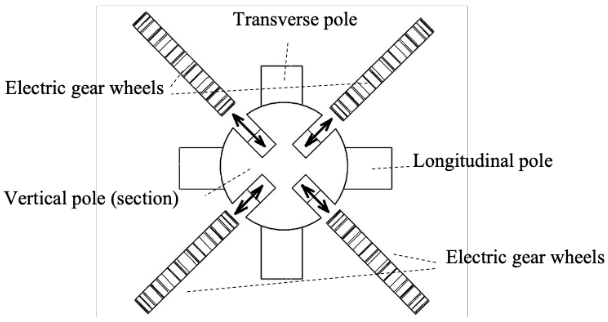


Fig.11 cross section view of electric gears and vertical pole

3. transverse movement

Figures 12 and 13 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.

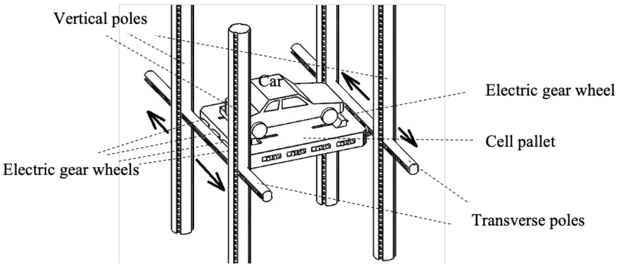


Fig.12 Schematic image of transverse movement

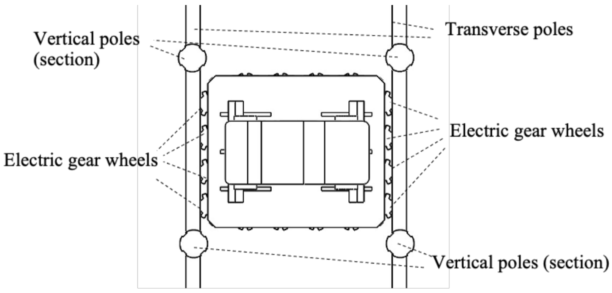


Fig.13 plan view of transverse movement

4. direction change

In the multi-story car park shown in Figure 4, pallets on the first floor can move in longitudinal and vertical directions but not in the transverse direction. On the second floor, transverse and vertical movements are possible, but longitudinal movements are not possible. In either case, vertical movement by one floor is necessary. Figure 14 which magnifies the part of Figure 4 shows that transverse poles which are positioned higher than the pallet allows the longitudinal movement on the first floor and that longitudinal 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.

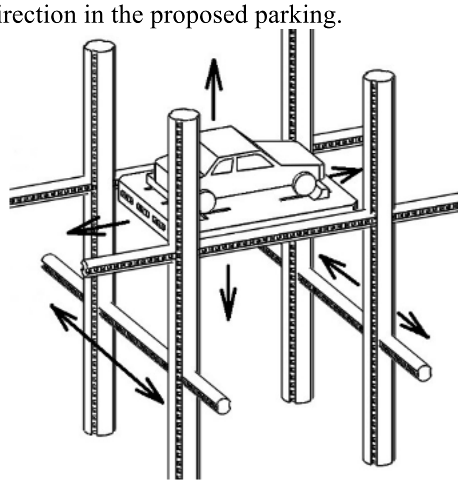

Fig.14 close-up view of three-axis movement

*C. Exit Operation*

The flow of the exit operation is the opposite of the entrance operation. The driver shows the parking slip to the operator in the control room, who in turn moves the cell pallet carrying the designated vehicle to the turntable. The mechanism of the pallet movement is the same as those described in Section 2.3.

## III. CONCLUSION

This paper proposes a multi-story parking lot that maximizes the capacity of the mechanical multi-story parking lot and greatly improves the utilization efficiency of the three-dimensional space. Using a cell pallet equipped with electrical gears, the vehicle is securely transported in and from the three-dimensional parking lot. The multi-story car park is composed of horizontal (longitudinal and transverse) and vertical poles. Gear racks embedded in these poles and the electric gear wheels on the pallets allow stable and efficient movement of the pallet and the vehicle on it. The proposed parking lot does not require slope to connect the adjacent levels and the height of one level is approximately half of that in existing multi-story car park. The proposed parking system is highly efficient in land usage with no slopes and double capacity in vertical direction.

There are two potential uses for the proposed multi-story car park.

- Temporary storage facilities for large number of vehicles.
- Car carries (special ships for car transportation)

In both cases, entrance and exit are conducted in short period of time. This time intensity allows for the operators to familiarize with pallet operations.

At this stage, the operation of the pallet is assumed to be conducted by the operator, but as the number of parked vehicles increases, the operation load of the operator increases. The future task of this research is to study a highly efficient automatic multi-story car park without requiring the manual operations.

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