Proposal of 3D elevator for skyscraper buildings

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Abstract
The number of skyscraper buildings is increasing mainly in big cities. The delay of elevators in these skyscrapers has become a major problem during busy times when commuting to work or returning home. In this study, a new type of elevator operation method is proposed to reduce this subject. An elevator car ('kago' in Japanese) that carries passengers is lifted up with a cable and only moves up and down in an ordinary elevator. However, the elevator car can move up and down, left and right, and forward and backward in this proposed elevator system. And, the car has electric gear wheels attached to the four corners (left and right, front and back of the car). It can run on electricity. Elevators dedicated to ascending and descending (these are called main elevators in this paper) and elevators capable of normal vertical movement are installed. The main elevators are fast (high-speed elevator) and these elevators are configured to stop only on floors with many users (for example, the 1st floor, 10th floor, 20th floor, etc.). Low-speed elevators will be operated between the floors where the high-speed elevators do not stop for both ascending and descending. Though there is one elevator car in a common elevator, there are multiple elevator cars in the proposed system. When it is crowded, those elevator cars can be moved from the left and right or front and rear, and it consists of multiple cars per unit (elevator) and can move for ascending and descending. When the number of passengers of an elevator decreases, the number of cars is adjusted by evacuating the car to the left and right, front and rear areas. The multiple cars in the left/right elevator or front/back elevator on the 1st floor can be stored. And, these cars can be stored in the left/right elevators or in the front and rear elevators on the top floor. With this three-dimensional elevator system, an elevator car that reaches the top floor in an elevator that only goes up is moved to an elevator for only going down. An elevator car that has reached the bottom floor in a down-only elevator is similarly moved to an up-only elevator (like drawing a loop). In addition, cameras are installed at each top front of ascending and descending elevators (main elevator) and they can count the number of people waiting. The number of elevator cars in operation is adjusted according to the number of passengers. This method can improve the time efficiency of the elevator.

Key words
elevator, elevator car, skyscraper, total elapsed time for all users, total distance traveled by elevator cars for all passengers

1. Introduction

There are the following famous skyscrapers in Japan. Most of them are located in urban areas.

- Toranomon Hills (Tokyo), Height 255.5 m, Highest floor 52nd floor, Number of elevators 53 (Toranomon Hills 2024)
- Yokohama Landmark Tower (Yokohama), Height 296.33 m, Highest floor 70th floor, Number of elevators 74 (Yokohama Landmark Tower 2024)
- Abeno Harukas (Osaka), Height 300.0 m, Highest floor 60th floor, Number of elevators 56 (Abeno Harukas 2024)
- Azabudai Hills Mori JP Tower (Tokyo), Height 325 m, Highest floor 64th floor, Number of elevators 71 (Azabudai Hills Mori JP Tower 2024)

It is necessary to install many elevators to quickly move many users to their destination floors. If the number of elevators installed increases, the space required for them will increase, and the cost of equipment will also increase. The main methods currently used to efficiently operate elevators in skyscrapers are the 'sky lobby method' and 'double-deck elevator method'. The 'sky lobby method' is used at Abeno Harukas. The number of elevators installed can be reduced in this method and transportation capacity can be secured. Passengers take a shuttle elevator from the 1st floor to a certain floor (sky lobby), and transfer to another elevator to get to their destination floor in this method. The shuttle elevator means an elevator that moves directly to a specific floor in this paper. For example, if there is a direct connection between the 1st floor and the 10th floor, passengers can travel back and forth nonstop between the 1st floor and the 10th floor.

The reasons for adopting the sky lobby method for elevators of skyscrapers are as follows:

- Transportation capacity can be secured with a small area.

- Users can comfortably reach upper floors.

As buildings and condominiums become taller, it is necessary to increase the number of elevators installed in order to ensure the transportation capacity of the elevators. However, as the number of elevators installed increases, the installation area also increases, which has the disadvantage of reducing the 'sales area' in commercial facilities. Additionally, the taller the building, the longer it takes for passengers to reach the higher floors. For example, consider moving from the 1st floor to an office on the 35th floor. If it were a normal elevator, it would stop up to 34 times, starting from the 1st floor, then to the 2nd floor, etc., when it is crowded. In the sky lobby method, passengers take a shuttle elevator from the 1st floor to the 30th floor sky lobby, then transfer to a regular elevator and move to the 35th floor. It is possible to reach the destination floor with a maximum of six stops according to this method, and it is possible to significantly reduce travel time (Sky Lobby System, 2024). However, the number of sky lobbies must be increased in order to reduce the number of elevator transfers and significantly shorten travel time. This method further reduces the available space and increases the costs.

The history of the sky lobby system is as follows. The John Hancock Center in Chicago (USA) was the first to adopt the sky lobby system for elevators (John Hancock Center 2024). This center was completed in 1969 and was approximately 344 meters above ground (100 floors).

The following describes the system of 'double-deck elevator.' Two elevator cars connect the top and bottom, and make it possible to transport many people at once in this system. It is a two-story elevator. It was first introduced in 1931 by Otis Elevator Company which was the world's largest elevator manufacturer. The distance between the upper car and the lower car can be adjusted, which is named 'floor adjustment function.' It can be installed in buildings where the ceiling heights vary from floor to floor.

The advantage of introducing the double-deck elevator is that people can ride in two cars (the top and bottom) at once. This system can improve transportation capacity by 1.5 to 1.9 times, and it reduces the long waits during hours when elevators are crowded (for example before and after business hours and around lunchtime). Additionally, it is possible to reduce the number of elevators installed and reduce the area ratio of the elevators to the building area. In office buildings, more office space can be rented out.

The double-deck elevator has both advantages and disadvantages. Namely, the lower car only stops on odd-numbered floors (1st floor, 3rd floor, 5th floor ...), and the upper car only stops on even-numbered floors (2nd floor, 4th floor, 6th floor ...). This is a structural issue for double-deck elevators. For this reason, the first and second floors are generally connected by an escalator, and those going to odd-numbered floors will take the elevator from the 1st floor and those going to even-numbered floors will take the car from the 2nd floor. When the above car stops on the 32nd floor and passengers are getting on and off, there is an announcement that says, "In the upper car, passengers are getting on and off. Please wait for a while" in the lower car and the passengers will have to wait until passengers in the car above have finished getting on and off (Double Deck Elevator, 2023). Furthermore, two cars must be used even if there are few users. It is a wasteful operation.

As an example of implementation in Japan, 16 double-deck elevators are in operation at Azabudai Hills Mori JP Tower (Azabudai Hills Mori JP Tower, 2024). This building is known as the tallest in Japan. However, the 'sky lobby method' and 'double-deck elevator' alone are not sufficient in order to operate the skyscraper's elevators efficiently. In this paper, a three-dimensional elevator system that improves the operational efficiency of elevators in skyscrapers is proposed.

2. Electric powered elevator car

An electric powered elevator car is a rectangular parallelepiped box similar to an ordinary elevator car, which is moved by electric gear wheels. The box (elevator car) is indicated in Figure 1. The electric gear wheels are installed on the left and right sides of the box, the front and back sides, and the four corners (there are multiple of each). The corners are flattened so that the electric gear wheels can come out from the four corners.

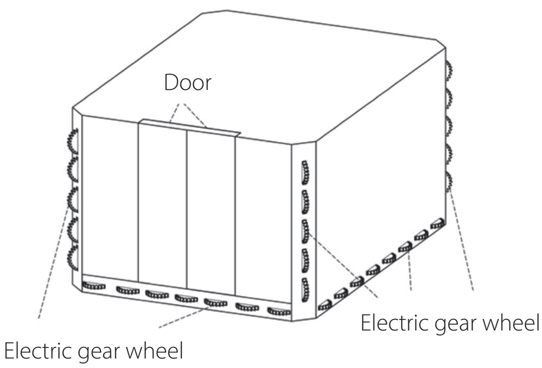

Figure 1: Proposed electric elevator car (box)

3. Three-dimensional elevator

There has been no elevator system that can move a car in three directions until now: left and right, up and down, and front and back. An elevator system in which the car is allowed movement in three directions is proposed in this paper, as shown below. This system is called a '3D elevator' in this paper. This paper is an applied study of the literature of Funase et al. (2022) which proposes a multi-level parking lot that makes maximum use of three-dimensional space. The

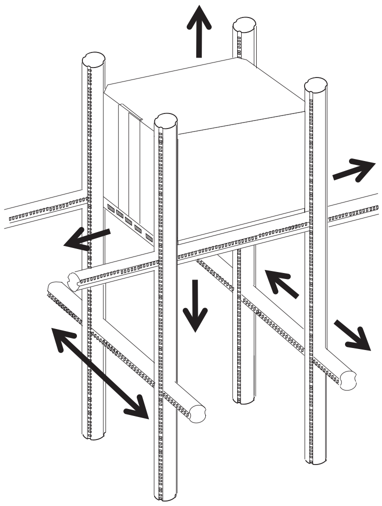

Figure 2: Electric box inside a 3D elevator system

proposed three-dimensional elevator system is composed of a skeleton of poles like a jungle gym and the electric box (car) moves inside it left and right, up and down, and front and back. The skeleton structure and the electric box inside the 3D elevator system is indicated in Figure 2.

Next, the operation of the electric box is explained specifically. When the electric box moves left or right, the box must be on an odd-numbered floor. At this time, only the electric gear wheels on the left and right sides of the box are risen, and the other electric gear wheels are retracted into the box. The state in which the electric gear wheels has entered the groove of the horizontal pole is explained in Figure 3. This is a cross-sectional view when viewed from above. In the figure, the electric gear wheel is pushed up when it passes a vertical pole and it is returned to its original position by a spring when it passes. The unevenness of the electric gear wheel and the side pole are perfectly meshed at that time. The electric wheel gear passing through the vertical pole is pushed up by the propulsive force of other electric gear wheels fitted in the horizontal poles.

When moving the electric box vertically, the box is moved to a position where the four corners are directly in front of the vertical pole. Thereafter, the electric gear wheels on the left and right sides and the ones on the front and back sides are retracted, and the electric gear wheels come out from the corners of the box and fit into the grooves of each vertical pole. The box can be moved up and down by this action. The wheels coming out of the corners and the way the vertical pole settles are the same as the horizontal movement due to the horizontal pole and the wheels. All parts fit neatly into irregularities. There are no poles to get in the way when moving.

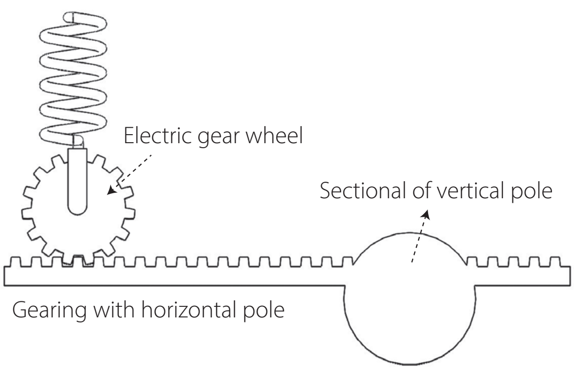

Figure 3: State in which electric gear wheel has entered groove of horizontal pole (cross section from above)

When the electric box moves back and forth, the box must be on an even numbered floor. It retracts the electric gear wheels on the left and right sides as well as the ones from the corners, and it takes out only the electric wheel on the front and back side and fits it into the groove of the front and rear poles. When it passes through the vertical pole, it is the same as when moving in the left-right direction, and the electric wheel is pushed up by the spring. In addition, this movement allows for forward and backward movement.

Next, the switching movement of the electric box from the other direction is described. Although the 3D elevator (car) shown in Figure 2 can move left and right and up and down on odd floors, it cannot move forward or backward as it is. This is because there are no front and rear poles (a kind of rail) and the side poles (pole extending left and right) prevent forward and backward movement of the car. On the other hand, the car can move forward and backward and up and down on even floors, however it cannot directly move left or right. The reason for this is that there are no horizontal poles that correspond to rails, and the front and rear poles prevent left and right movement. In order to execute such movements that cannot be performed directly, it is possible to do so by moving the car up and down by an odd number of floors in the vertical direction. The three-dimensional elevator shown in Figure 2 is stopped at an odd-numbered floor. This action allows the car to move freely left and right, up and down, and forward and backward in the three-dimensional elevator.

4. Elevators for skyscraper buildings

The elevator system for skyscrapers proposed in this paper is shown in Figure 4. It is desirable that the top floor is an odd numbered floor. An additional floor can be added for the elevator section if the top floor is even. Only elevators that can move left, right, and up and down are used. The series of elevators shown in Figure 4 are side by side. However, the same operation is possible by using an elevator that moves back and forth, and up and down if they are lined up one behind the other. There are high-speed type elevators and low-speed type elevators in the elevator system. A low-speed elevator can be used for both ascending and descending operations. There are two types of high-speed elevators. One

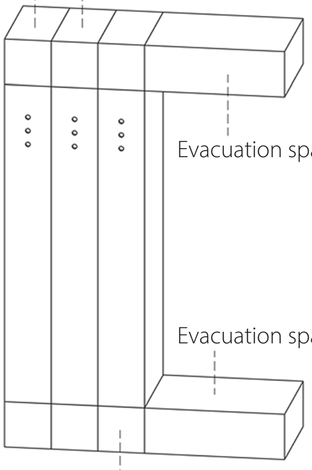

Figure 4: Elevator system for skyscrapers proposed in this paper

is for ascending and another is for descending. A camera is installed at the top of the front of each high-speed elevator to count the number of passengers waiting. Although passengers can only get on and off the high-speed elevators on predetermined floors, the control can be changed so that they can stop at any floor when the number of users per unit time is small. Elevator passengers will be notified of this control change using lamps inside and outside of the elevator. The number of electric boxes for high-speed elevators will be increased or decreased depending on the increase or decrease in the number of passengers. A smaller electric box is used when there are fewer passengers. The evacuation space for the electric box will be used when the number of high-speed elevators is increasing or decreasing. The same applies when switching to a small electric box. In addition, a pair of elevators for high-speed ascent and for high-speed descent constitutes a loop. The high-speed elevator should only stop on floors where there are many users (for example, the 1st, 10th and 20th floors, etc.). The low-speed elevator will be operated as an ascending and descending elevator between the floors where the high-speed elevator does not stop. Although the normal elevator system only has one box per unit to carry passengers, the proposed system can operate multiple electric boxes. In other words, a spare electric box is moved from the evacuation space of the boxes when it is crowded and multiple electric boxes are used for vertical movement. Some electric boxes will be moved to the evacuation space when the number of users decreases, and the number of electric boxes that move up and down will be reduced. And, the electric box is moved to the top floor using the ascent elevator, and is then moved to the decent elevator using the left or right elevators. Similarly, the electric box that has been moved to the bottom floor by the descending elevator is moved to the ascending elevator by the elevator either left or right. Cameras installed at the top of the front of the ascending elevators and descending elevators count the number of passengers waiting, and the system adjusts the number of electric boxes in operation accordingly. This method can improve the time efficiency of the elevator system.

The main advantages of the 3D elevator for skyscrapers proposed in this paper are the following two points:

- It is possible to have multiple boxes per unit (elevator system) instead of the conventional one box per unit, and the number of boxes can be increased or decreased depending on the number of passengers.
- The following elevators are prepared: ascending and descending only at high speed, and ascending/descending combined elevators at low speeds.

5. Conclusion

This study is applied to a study by Funase et al. (2022) on multi-story parking lots. An electric pallet called a cell pallet that can put one passenger car is prepared, and a multi-story parking lot that can make the most of three-dimensional space was proposed. A method to realize a three-dimensional elevator system is constructed in this paper and the proposed elevator system for skyscrapers is explained.

In the proposed system, a pair of adjoining high-speed ascent and descent elevators are used as a new elevator system for skyscrapers instead of the sky lobby system which is conventionally used. A loop is constructed by the vertical and horizontal movements of a three-dimensional elevator in this method. The proposed elevator system utilizes multiple boxes in one elevator unit, and can increase or decrease the number of boxes depending on the number of passengers, instead of double-deck elevators (two-story elevators) that can carry many people at once.

This elevator system utilizes elevators dedicated to ascending and descending which work fast. Although many shuttle elevators have been required in skyscrapers, this proposed system allows the operation with a minimum number of elevators. This system can also handle large numbers of passengers that cannot be handled by double-deck elevators. When the number of passengers is few, the wasteful transportation caused in double-deck elevator system can be avoided.

Future challenges include realizing the high-speed elevator system using electric gear wheels and safety.

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