Technical Report

Efficiency comparison of 3D elevators for skyscrapers using simulations

Haruhiko Kimura (Faculty of Transdisciplinary Sciences for Innovation, Kanazawa University, kimuraharuhiko05@gmail.com, Japan)
Kazuya Okada (Graduate School of Science and Engineering, University of Toyama, okada.k153@gmail.com, Japan)
Takashi Oyabu (Nihonkai International Exchange Center, oyabu24@gmail.com, Japan)
Shigeki Hirobayashi (Faculty of Engineering, University of Toyama, hirobays@eng.u-toyama.ac.jp, Japan)
Hidetaka Nambo (Graduate School of Natural Science and Technology, Kanazawa University, nambo@blitz.ec.t.kanazawa-u.ac.jp, Japan)

Abstract

Skyscrapers are being built all over the world so that land can be used more effectively in urban areas. This trend will continue in the future. Land prices in urban areas are high, and it is necessary to make buildings high-rise in order to lower the price per unit floor area. New problems arise as buildings become taller. For example, how to efficiently move as many persons (users) as possible to destination floors within a building during work hours and leaving hours. Even outside of those time zones, the following issue can be cited as an example. That is, how to move a small number of persons to a destination floor at low cost. The authors of this research have previously proposed a three-dimensional elevator-system for skyscrapers to solve this problem. However, the analysis regarding efficiency was not performed. In this study, a comparison of the efficiency of a 3D elevator system for skyscrapers using simulations is reported. The 'average user elapsed time' when commuting to work was calculated specifically by simulation and compared for each type of elevator system. The results showed that the 3D elevator system was clearly more efficient than the regular high-rise building elevator system.

Key words
skyscraper, three-dimensional elevator system, electric box, average waiting and ride time for elevator users, average operational time for high-speed elevator

1. Introduction

Many elevators are needed to move many users quickly to desired floors in skyscrapers (Abeno Harukas, Azabudai Hills Mori JP Tower, John Hancock Center, Toranomon Hills, Yokohama Landmark Tower, etc). When the number of elevators increases, it requires more space and costs. Currently, the following two methods are mainly used to efficiently operate high-rise elevators, namely the sky lobby system (Sky Lobby System, 2024) and the double-deck elevator (Ainichi, 2023). First, the sky lobby system (Figure 1) is explained. This system is used in the Abeno Harukas building in Osaka, Japan (Abeno Harukas, 2024), reducing the number of elevators installed while maintaining transportation capacity. The users take a shuttle elevator from ground level to a certain floor (sky lobby) then transfer to another elevator and move to the destination floor in this sky lobby system. Here, the shuttle elevator refers to an elevator that goes directly to a specific floor. For example, an elevator that directly reaches the 1st and 10th floors shuttles back and forth nonstop between the 1st and 10th floors. There are two possible reasons for adopting the sky lobby method for high-rise elevators: 'to secure transportation capacity in a small area' and 'for users to reach higher floors comfortably.' Normally, as a building or condominium becomes higher, more elevators must be installed to ensure sufficient transport capacity. When the number of elevators installed increases, the installation area also increases. If it is a commercial facility, the disadvantage is that the sales floor area will be reduced. And, the taller the building, the longer it takes for users to reach the higher floors. For example, consider moving from the 1st floor to an office on the 35th floor. If a regular elevator is used, it will stop up to 34 times when it is crowded, going to the 1st floor, then to the 2nd floor, etc. On the other hand, if users use the sky lobby method, a shuttle elevator takes the user from the 1st floor to the sky lobby on the 30th floor and then transfer to a regular elevator. After that, if a user moves to the 35th floor, the destination floor can be reached in up to six stops. It is possible to significantly reduce travel time (Sky Lobby System, 2024). However, in order to significantly reduce travel time while keeping the number of elevator transfers low, the number of sky lobby elevators must be increased. Increasing the num-

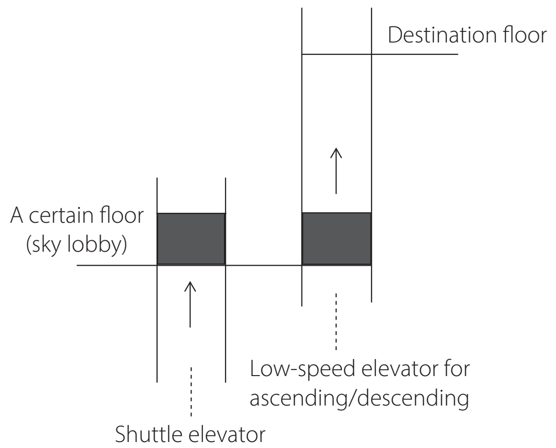

Figure 1: Sky lobby system

ber of elevators reduces the usable space and increases the costs.

Next, the double-deck elevator system (Figure 2) will be explained. It is an elevator system in which two elevator boxes (called '*kago*' in Japanese) are connected one above the other. The elevator system is capable of carrying many people at once and it is two-story elevator. It was first introduced in 1931 by Otis Elevator Ltd which was the world's largest elevator manufacturer. The distance between the upper box and the lower box can be adjusted. This function is called 'floor adjustment function'. The system can be installed in buildings with different ceiling heights on each floor. The advantage of introducing this system is that people can ride in two cars (the top and bottom) at once. This will increase transportation capacity by 1.5 to 1.9 times and reduce the long waiting times before 9 a.m. every morning (before work hours) and around 12 noon (lunchtime). Elevators are crowded during those hours. And the number of elevators installed can be reduced, and the number of elevators to the building area can also be reduced. This system can create more working space especially in office buildings. However, the double deck elevator system has not only advantages but also disadvantages. Because of the structure of the double-deck elevator, the lower car (box) is on odd-numbered floors (e.g., 1st, 3rd, 5th, etc.) and the upper car is on even-numbered floors (e.g., 2nd, 4th, 6th, etc.), and each box has a limited number of floors to stop on. Therefore, the first and second floors are connected by an escalator, and people going to odd-numbered floors board from the 1st floor, and people going to even-numbered floors board from the 2nd floor. Further, when the upper car is stopped at the 32nd floor, for example, and a person is getting on or off the car, the lower car makes an announcement saying, "The other car is now in service." The users have to wait until the top car is loaded and unloaded (Ainichi, 2023). And even when there are few users, two cars must be used, and it results in waste. As an example of its introduction in Japan, 16 double-deck elevators are in operation at Azabudai Hills Mori JP Tower in Tokyo, which is known as the tallest building in Japan (Azabudai Hills Mori JP Tower, 2024). In order to operate super high-rise elevators efficiently, the "sky lobby system" and "double-deck elevator" alone are insufficient. The idea of a "three-dimensional elevator (3D)" was devised to make up for the shortcomings (Kimura et al., 2024).

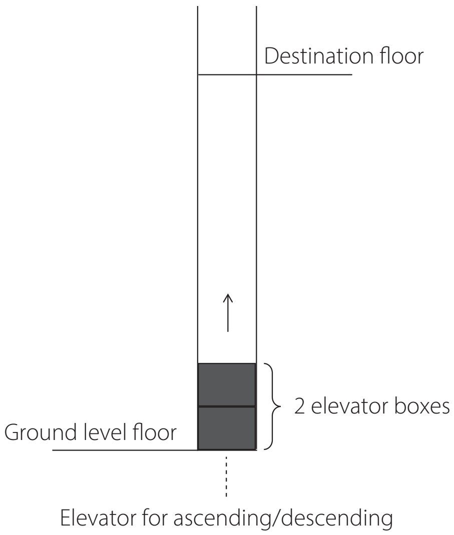

Figure 2: Double-deck elevator system

In a normal elevator system, the cars that carry passengers are lifted by cables and only move up and down. In the 3D elevator, there are electric gears on the left and right, front and rear, and four corners of the car (electric car), allowing it to move left and right, front and back, and up and down. The main elevators are used exclusively for ascending and descending in this elevator system, and other elevators that can also be used for normal vertical movement are also used. Elevators exclusively for ascending and for descending are high-speed elevators. These elevators only stop on the floors with the most passengers (for example, the 1st floor, 10th floor, 20th floor, etc.). The elevators (low-speed elevators) that can go up and down will be operated on the floors where high-speed elevators do not stop. These low-speed elevators are operated separately from the other elevators exclusively for ascending and for descending. Ordinary elevator systems only have one car (box) for carrying passengers. The 3D elevator can operate multiple electric boxes per system. The boxes can be moved from the electric box evacuation space on the right side or rear of the top floor or first floor during times of congestion, and multiple boxes can be used to move up and down. Additionally, some electric boxes can be evacuated to the evacuation space when the number of users decreases, and the number of electric boxes that are moved up and down can be adjusted. The electric box, which is moved to the top floor using an elevator that only goes up, can also be used as an elevator that goes down according to the 3D elevator. Similarly, the electric box that has been moved to the bottom floor by the downward elevator is transferred to the upward elevator by the 3D elevator. The number of passengers waiting is counted by a camera mounted on the top of the front of the elevator for going up and going down. The number of electric boxes in operation is adjusted according to the number of passengers. This makes it possible to improve the time efficiency of the elevator system. The efficiencies of three types of elevator systems for skyscrapers are compared using a simulation in this study.

2. Three-dimensional elevator

A rectangular box which corresponds to an elevator car, is moved by an electric gear. This is called an electric box. The electric box is shown in Figure 3 (Kimura et al., 2024). Plural electric gears are installed on the left and right sides of the box, the front and rear sides, and the four diagonal corners.

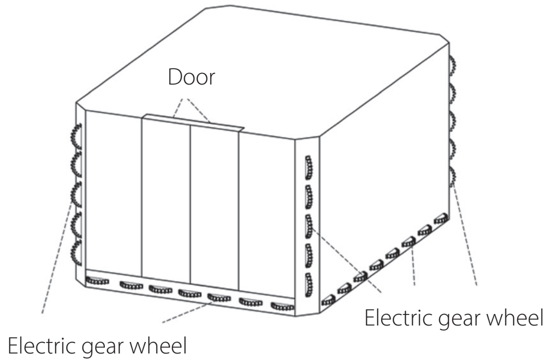

Figure 3: Electric box
Source: Kimura et al. (2024).

The corners are flattened so that the electric gears can come out from the four corners.

There is no elevator system that can move the box in three directions up to now, namely left and right, front and back, and up and down. An elevator system that allows the movement in three directions was proposed in a previous study (Kimura et al., 2024). Such an elevator will be referred to as a 3D elevator in this paper. This is an application of multilevel parking research that makes maximum use of three-dimensional space (Funase et al., 2022). The 3D elevator system is made up of skeleton poles that look like a jungle gym (Kimura et al., 2024). It is shown in Figure 4. The electric box moves left and right, front and back, and up and down inside the jungle gym. The electric box inside the 3D elevator is shown in Figure 5.

When the electric box moves left or right, the box must be on an odd-numbered floor. Only the electric gears on the left and right sides of the box should be outside, and the other gears should be stored inside the box. The state that the electric gear and side pole are fitted into the grooves, is indicated in Figure 6. This is a cross-sectional view when seen from above. When the electric gear passes through the vertical pole, it is pushed up. When it passes, it is returned to its original position by a spring and the unevenness of the gear and side pole is stored well. In addition, when the electric gear passes through the vertical pole, it is pushed up by the propulsive force of other electric gears housed in the horizontal pole.

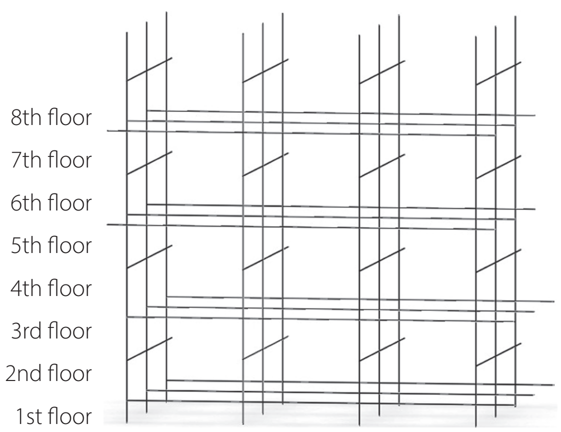

Figure 4: Skeleton diagram of the proposed 3D elevator (move left and right 3 units, move up and down 8 units, move forward and backward 2 units)
Source: Funase et al. (2022).

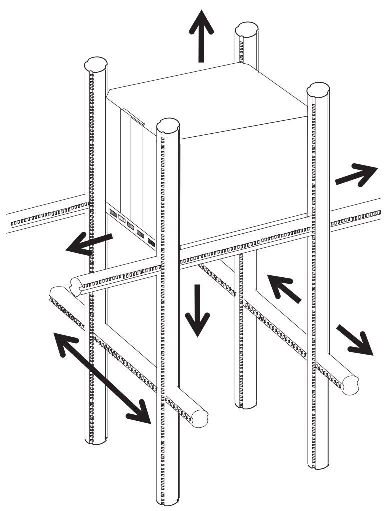

Figure 5: Electric box inside the 3D elevator
Source: Kimura et al. (2024).

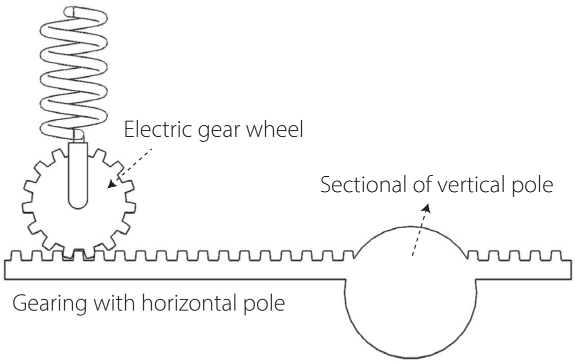

Figure 6: Storage of electric gear and side pole groove (cross section from above)
Source: Funase et al. (2022).

When the electric box is moved in the vertical direction, the box is moved to the position where the four corners are directly in front of the vertical pole. After that, the electric gears on the left and right sides and the ones on the front and back sides are retracted, and those gears are brought out from the four corners and stored in the grooves of each vertical pole. This action allows the electric box to move up and down. Furthermore, the electric gears coming out of the four corners and the vertical pole are stored in the same manner as the horizontal pole and the electric gear moving in the left and right direction, and are stored in the unevenness. There are no poles obstruct when moving.

When an electric box moves forward or backward, the box must be on an even numbered floor. The electric gears on the left and right sides and the ones from the four corners are pulled back, and only the electric gears on the front and rear sides are brought out and stored in the grooves of the front and rear poles. When the electric box passes through the vertical pole, it is the same as moving left and right, namely the electric gear is pushed up by the spring. This movement enables movement in the front-back direction.

Next, the switching movement from the other direction will be described. In the 3D elevator shown in Figure 4, the elevator can move horizontally and vertically on the 1st floor, but cannot move forward or backward in its current state. Also, the movement is possible in the front-back direction and up-down direction on the 2nd floor, but the movement in the left-right direction is not possible directly. To perform such a movement, it becomes possible due to movement up or down on only odd-numbered floors in the vertical direction. It is the same as being on the 1st floor when the 3D elevator is on an odd-numbered floor in Figure 4. When it is on an even-numbered floor, it is the same as being on the 2nd floor. Also, the reason why it is not possible to move forward and backward on the 1st floor is because the front and rear horizontal poles block the forward and backward movement of the electric box. This is because there is not a pair of horizontal poles in the front and rear directions that serve as rails for movement. Similarly, the reason why it is impossible to move left and right on the 2nd floor is because the left and right side poles block the left and right movement of the electric box. Furthermore, this is because there is not a pair of horizontal poles in the left and right directions that serve as rails for movement. These movements allow the electric box to move freely left and right, up and down, and forward and backward in the 3D elevator system.

3. 3D high-rise elevator systems for comparison

Three high-rise elevators to be compared are described below.

3.1 Ordinary high-rise building elevator

The schematic diagram of the general elevator (G-type) for high-rise buildings that is the subject of this study is shown in Figure 7. This system is equipped with two high-speed elevators for ascending/descending and two low-speed elevators for ascending/descending. These high-speed ascending/descending elevators only stop at the 1st, 10th, 20th, 30th, etc. floors. The low-speed ascending/descending elevators stop at each floor: 1st floor, 2nd floor, 3rd floor, etc. This elevator system uses a high-speed ascending/descending elevator to quickly stop at the destination floor or a nearby floor. Afterwards, the passenger moves to the destination floor using the low-speed elevator for ascending and descending. This method has the following drawbacks: the passengers who

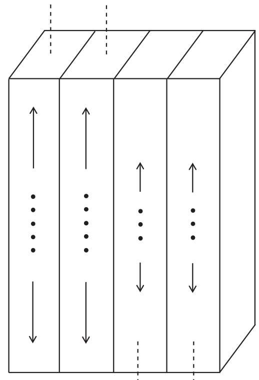

Figure 7: General high-rise building elevator

are unable to board a high-speed elevator will need time to wait for the next high-speed elevator. In other words, the high-speed elevator that has reached the top floor or near the top floor must be returned to the 1st floor. The higher the skyscraper, the longer the time it will take. Furthermore, if the number of low-speed elevators is small, the distance between floors (from the 1st floor to the top floor) is long, so it takes much time.

3.2 3D elevator type A

The outline of the 3D elevator type A (A-type) that is the subject of this study is shown in Figure 8. This type has one elevator for high-speed ascents, one elevator for high-speed descents, and two elevators for low-speed ascents and descents. In addition, the elevators for high-speed ascents and elevators for high-speed descents are linked (forming a loop), and the electric boxes are provided for both elevators. There is an electric box evacuation space in the basement of the high-speed elevator, which can accommodate several electric boxes. The electric box of the high-speed elevator stops only at the 1st floor, 10th floor, 20th floor, 30th floor, etc. It is possible to increase or decrease the number of electric boxes in both high-speed elevators. Low-speed ascending/descending elevators assign electric boxes to each limited floor, such as 1st to 9th floor, 10th to 19th floor, 20th to 29th floor, etc., and move only between those floors. For example, the third electric box assigned can move only between the 20th and 29th floors. Furthermore, the advantage of the high-speed dedicated elevator described here is that the number of passengers can be counted using a camera on the 1st floor, and the necessary number of electric boxes can be prepared from the electric box evacuation space. Also, it is obvious which high-speed elevator each passenger should take since there is a fixed elevator for ascending/descending. Furthermore, the average waiting time for low-speed ascending/descending elevators is shortened because electric boxes are assigned to each limited floor. Therefore, the passengers

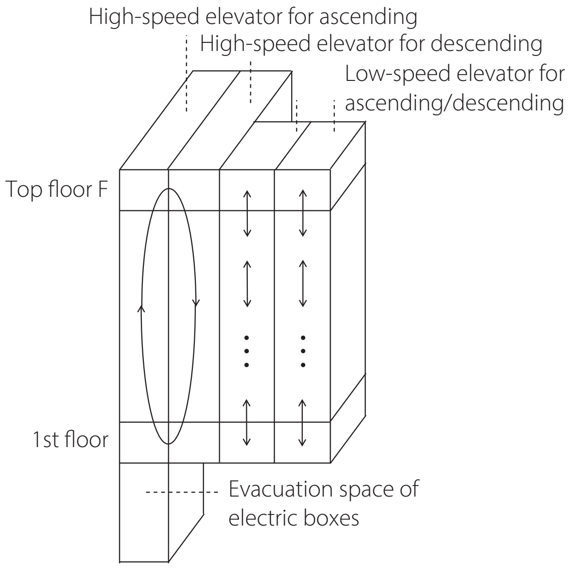

Figure 8: 3D elevator type A

can reach their destination floors faster than the general elevator for high-rise buildings. In addition, in this system the passengers are not forced to wait on the 1st floor because they cannot fit into the box. The electric boxes that match the number of passengers will operate in succession. However, the doors of each connected electric box will not close unless a predetermined number of passengers get on board. These situations will be announced automatically.

3.3 3D elevator type B

The schematic diagram of the 3D elevator type B (B-type) targeted in this study is shown in Figure 9. This system consists of one elevator for high-speed ascending, one elevator for high-speed descending, one elevator for low-speed ascending, and one elevator for low-speed descending. The high-speed elevator is the same as the 3D elevator type A, and it forms a loop (loop elevator). The elevator can only stop on the 1st, 10th, 20th, 30th floors, etc. Additionally, it is possible to increase or decrease the number of electric boxes in both the high-speed ascending elevator and descending elevator, so the passengers will not have to wait. Furthermore, electric boxes are assigned to each limited floor: 1st to 9th floors, 10th to 19th floors, 20th to 29th floors, etc. And, the electric box is circulated in the order of the elevator for low-speed ascent and the elevator for low-speed descent (loop elevator). The advantages of this B-type high-speed elevator are the same as those of the A-type. In addition, the low-speed elevators also have electric box evacuation spaces, so the electric boxes can be added or removed, and passengers will not have to wait. Furthermore, it is easy to know which high-speed elevator a passenger should take since it is decided whether the elevator is going up or down. The average waiting time for low-speed elevators is shorter than the one for general high-rise building elevators because electric

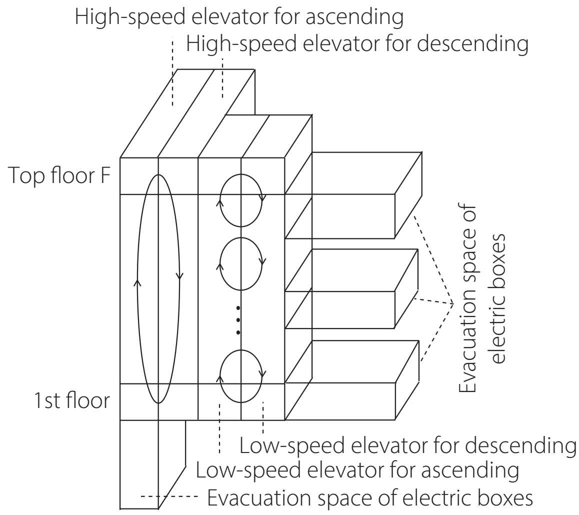

Figure 9: 3D elevator type B

boxes are assigned to each limited floor.

4. Definitions

[Definition 1]

If the top floor is an even numbered floor, an additional floor will be added to switch from a high-speed ascending elevator to a high-speed descending elevator. Furthermore, it is assumed that the initial position of the electric box of each elevator is at the lowest floor between the target floors.

Define 'average user elapsed time (AET)' when going to work as follows:

$$\mathrm{AET} = \mathrm{TET} / n \quad (1)$$

Here, TET means the total elapsed time of all passengers. Namely, it is the total elapsed time for all passengers to reach the destination floor using the elevator system. It is assumed that each target floor is determined by uniform random numbers. The travel time of high-speed elevators for both ascending and descending is t_1 (unit time/floor). The travel time of the low-speed elevators for both ascending and descending is t_2 (unit time/floor). It takes time to transfer from an elevator only for ascending to an elevator only for descending, or from an elevator only for descending to an elevator only for ascending, both in high-speed elevators and low-speed elevators. This time is indicated as t_3 (unit time/number of transfers). The n is the number of passengers waiting on the first floor.

The 'average user elapsed time for high-speed elevators (AE1)' and the 'average user elapsed time for low-speed elevators (AE2)' at the time of going work are defined as follows:

$$\mathrm{AET} = \mathrm{AE1} + \mathrm{AE2} \quad (2)$$

Here, AE1 is the average elapsed time required by AET for high-speed elevators. AE2 is the average elapsed time required by the low-speed elevator.

[Definition 4]

The average user elapsed time (AE2) of a low-speed elevator in a general high-rise building elevator is calculated as follows. However, this does not include the time it takes to return an electric box to AA(i) when all passengers cannot ride on one electric box.

$$AE2 = t_2 \cdot \Sigma n_{i=1} (|AA(i) - F / 2| + A(i) - AA(i)) / n \quad (3)$$

Here, A(i) is the floor targeted by the i-th passenger (user). AA(i) is the floor where the i-th user gets off the high-speed elevator. In other words, this is the floor where the user needs to transfer to the low-speed elevator. F is the top floor.

[Definition 5]

Three types of elevators are compared. The maximum number of people per electric box is 20 for high-speed elevators and the capacity of the low-speed elevator is 10 people. A camera is attached to the top of the door of the ascent elevator for high-speed access on the 1st floor. The camera counts the total number of passengers waiting for the elevator just before the elevator doors open. It is determined automatically how many electric boxes for high-speed elevators are required. It is assumed that no one enters any elevator from an intermediate floor.

[Definition 6]

$p * t_4$ (unit time) is the time required for p users to get on and off the elevator (high-speed and low-speed). However, boarding the elevator is limited to the lowest floor between the 1st floor and the target floor.

[Definition 7]

In a high-speed elevator, if the destination floor is A, it is assumed that the passenger will get off at the floor of INT (A/10) · 10. INT(x) means the value of x with the decimal part removed. For example, INT (A/10) · 10 becomes the 70th floor when A = 72nd floor. Furthermore, if the destination floor is single digits, the high-speed elevator will not be used, and the low-speed elevator will only be used.

As mentioned in Definition 7, when the passenger gets off at the S-th floor using a high-speed elevator, the destination floor is either the S-th floor, the S + 1st floor, the S + 2nd floor . . ., or the S + 9th floor. At this time, the question is what floor the low-speed elevator is on, but it could potentially be on any floor between those floors. Therefore, the average is taken and it is assumed that the elevator is in the middle of the floors (between those floors).

[Definition 9]

In the 3D elevator A-type and B-type, the time required to add or remove one high-speed electric box is assumed to be t_5 (unit time/floor). In addition, the time required to add or remove one electric box of a low-speed elevator is assumed to be t_6 (unit time/floor).

5. Experiment

The efficiencies of three types of elevator systems are compared. The target elevator types are the following three types.

- General high-rise building elevator (G-type)
- 3D elevator type A (A-type)
- 3D elevator type B (B-type)

In this paper, the 'average user elapsed time' when commuting to work are determined through simulation. Here, the values of t_1, t_2, . . ., t_6 were set to 2, 5, 15, 1, 22, 15 (unit time), respectively. The reason $t_3 = 15$ is that the top floor is an even number, so the electric box goes up one floor, moves one unit to the side, and then goes down one floor. In addition, t_5 is set to 22 because 20 people can get into the high-speed electric box and go up one floor. Furthermore, t_6 is set to 15 because 10 people can get into the low-speed electric box and go up one floor.

[Experiment 1]

The average user elapsed time per user when commuting to work for a general high-rise building elevator (G-type) is determined using the Monte Carlo method. It is assumed that the passenger gets on the elevator from the 1st floor and goes to the destination floor determined by uniform random numbers (simulation). Furthermore, when getting off the high-speed elevator and transferring to the low-speed elevator, the low-speed elevator may be located on any floor. Therefore, the average distance is derived and it is assumed that the elevator is on the F/2nd floor (F: the top floor). Some passengers may not be able to get into the electric box when transferring to a low-speed elevator. In this case, the waiting time for the next electric box to arrive is assumed to be $t_2 \cdot$ F/2 unit time. Here, the highest floor F that can be arrived at with the high-speed elevator is changed to F = 10th floor, 20th floor, . . ., 100th floor. Also, it is derived the change in the average user elapsed time at commuting time to work, when the total number of target passengers n is increased to n = 10, 20, . . ., 100.

(Experiment results)

The flowchart for determining the changes in AE1, AE2, and AET per passenger is shown in Figure 10, when commuting to work in a general high-rise building elevator. The execution results are shown in Figure 11, Figure 12, and Figure

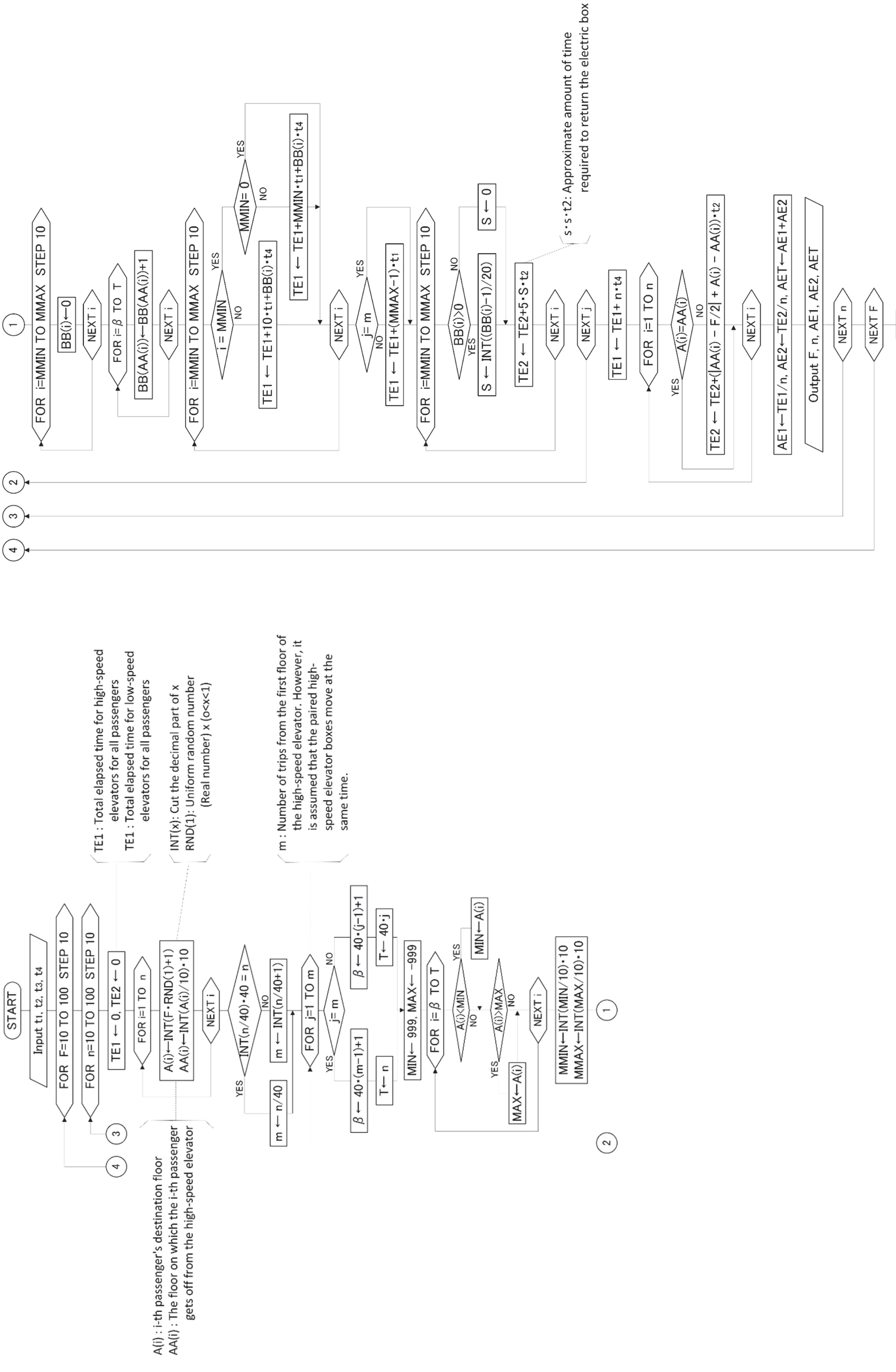

Figure 10: Flowchart for deriving the changes in average user elapsed time for general high-rise building elevator system

Top floor (F) \ Number of passengers (n)	10	20	30	40	50	60	70	80	90	100
100	20	11	7	6	13	11	10	9	12	10
90	15	9	7	6	11	10	8	8	10	10
80	15	8	7	5	10	9	8	7	10	9
70	13	7	6	4	9	8	7	6	8	8
60	12	7	5	4	8	6	6	5	8	7
50	9	5	4	4	7	6	5	5	7	6
40	7	4	3	3	5	5	5	4	5	4
30	5	3	3	2	4	4	4	3	5	4
20	3	3	2	2	4	3	3	2	3	3
10	3	2	1	1	1	2	1	1	2	2

Figure 11: Changes in average user elapsed time for high-speed elevator per passenger when commuting to work compared to general high-rise elevator

Top floor (F) \ Number of passengers (n)	10	20	30	40	50	60	70	80	90	100
100	122	140	143	118	125	127	155	139	137	132
90	100	149	127	115	125	111	127	133	133	140
80	102	99	112	109	121	108	101	120	117	107
70	105	105	105	105	108	106	95	110	101	103
60	38	86	94	116	89	96	101	82	80	101
50	101	80	80	83	82	85	86	84	79	82
40	73	65	56	66	74	56	71	77	62	68
30	65	54	57	47	52	65	59	60	56	64
20	45	42	51	44	37	43	43	52	42	50
10	46	46	47	45	49	47	48	45	47	45

Figure 12: Changes in average user elapsed time for low-speed elevators per passenger when commuting to work compared to general high-rise elevators

Top floor (F) \ Number of passengers (n)	10	20	30	40	50	60	70	80	90	100
100	142	151	150	124	138	138	165	148	149	142
90	115	158	134	121	136	121	135	141	143	150
80	117	107	119	114	131	117	109	127	127	116
70	118	112	111	109	117	114	102	116	109	111
60	50	93	99	120	97	102	107	87	88	108
50	110	85	84	87	89	91	91	89	86	88
40	80	69	59	69	79	61	76	81	67	72
30	70	57	60	49	56	69	63	63	61	68
20	48	45	53	46	41	46	46	54	45	53
10	49	48	48	46	50	49	49	46	49	47

Figure 13: Changes in average user elapsed time per passenger when commuting to work for general high-rise building elevator

13. The unit here means unit time.

[Experiment 2]

The average user elapsed time per passenger when commuting to work for the 3D elevator A-type is determined using the Monte Carlo method. It is assumed that the passenger gets on the elevator from the 1st floor and gets off at the destination floor determined by uniform random numbers. The low-speed elevator is assumed to be on the F/2nd floor (F: top floor) when the passenger is getting off the high-speed elevator and transferring to the low-speed elevator. When transferring to a low-speed elevator, if there are passengers who cannot fit into the electric box, the waiting time for the next electric box to arrive will be $t_2 \cdot F/2$ seconds per elevator. The top floor F where a passenger can get off the high-speed elevator is changed to F = 10th floor, 20th floor, . . ., 100th floor. Furthermore, the total number of target passengers is increased, namely n = 10 persons, 20 persons, . . ., 100 persons. And the change in the average user elapsed time when commuting to work due to these states change is derived.

(Experiment results)

A flowchart for deriving changes in AE1, AE2, and AET at the time of work for the A-type is shown in Figure 14. The execution results are shown in Figure 15, Figure 16, and Figure 17. The unit is unit time.

[Experiment 3]

The average user elapsed time per passenger at the time of commuting to work for the 3D elevator B-type is derived using the Monte Carlo method. However, it is assumed that the passenger gets on an elevator on the 1st floor and goes to the destination floor determined by uniform random numbers. Furthermore, when getting off a high-speed elevator and transferring to a low-speed elevator, the low-speed elevator is assumed to be on the F/2nd floor. The top floor F that a passenger can get off the high-speed elevator could be changed to F = 10th floor, 20th floor, . . ., 100th floor. Also, the changes in the average user elapsed time when commuting to work are derived when the total number of target passengers n is increased to n = 10, 20, . . ., 100.

(Experiment results)

A flowchart for deriving changes in AE1, AE2, and AET at the time of work for the B-type is indicated in Figure 18. The results are shown in Figure 19, Figure 20, and Figure 21. The unit is unit time.

6. Conclusion

The experiment conducted in this study assumed that elevators were used during the most crowded time of work. It is thought that there is a particular definition of 'crowded' when using an elevator. The crowded situation can be understand through intuitive judgment. The issue is not whether there are many or few passengers using the elevator system. The issue is how quickly the passenger can get on the elevator and arrive at the destination floor in the least amount of

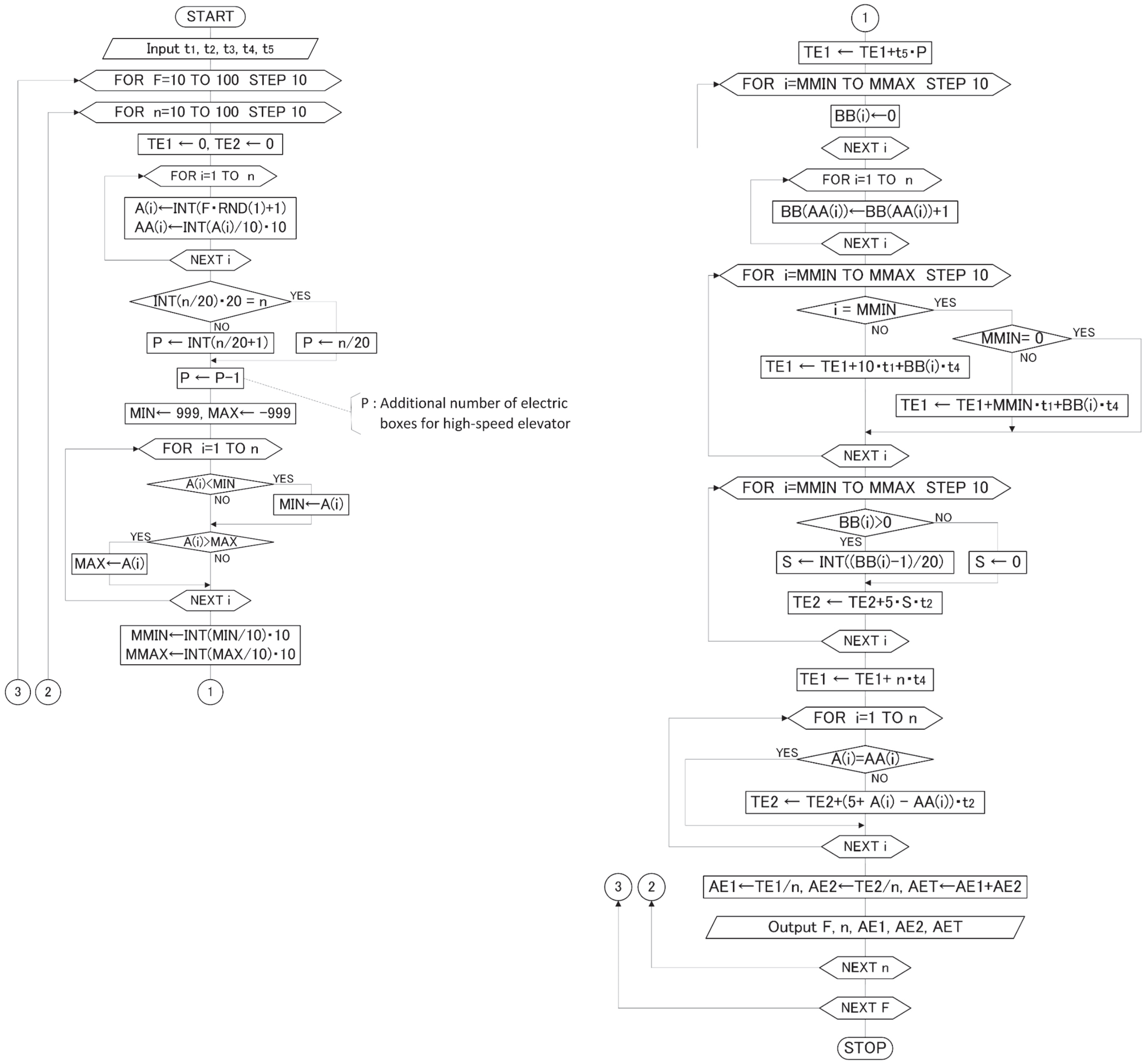

Figure 14: Flowchart for deriving the change in average user elapsed time for 3D elevator A-type

Top floor (F) \ Number of passengers (n)	10	20	30	40	50	60	70	80	90	100
100	20	11	8	7	6	5	5	5	5	4
90	15	9	7	6	5	5	5	4	4	4
80	15	8	7	5	5	5	5	4	4	4
70	13	7	7	5	5	4	4	4	4	4
60	12	7	6	4	5	4	4	3	4	3
50	9	5	5	4	4	4	3	3	3	3
40	7	4	4	3	4	3	3	3	3	3
30	5	3	4	3	3	3	3	3	3	3
20	3	3	3	3	3	2	3	2	3	2
10	3	2	2	2	2	2	2	2	2	2

Figure 15: Changes in average user elapsed time for high-speed elevator per passenger when commuting to work for 3D elevator A-type

Top floor (F) \ Number of passengers (n)	10	20	30	40	50	60	70	80	90	100
100	37	48	49	43	40	43	43	46	44	43
90	40	51	38	41	44	40	47	43	48	45
80	52	45	46	45	46	45	42	46	44	43
70	40	45	43	43	44	44	45	44	44	45
60	38	43	49	51	42	44	48	44	43	47
50	51	45	45	48	45	45	46	42	42	44
40	43	45	45	46	49	38	48	48	44	45
30	45	39	41	40	43	46	45	48	43	49
20	55	42	45	47	43	45	46	50	46	49
10	46	46	47	45	49	47	48	45	47	45

Figure 16: Changes in average user elapsed time for low-speed elevator per passenger when commuting to work for 3D elevator A-type

Top floor (F) \ Number of passengers (n)	10	20	30	40	50	60	70	80	90	100
100	57	59	57	50	46	48	48	51	49	47
90	55	60	45	47	49	45	52	47	52	49
80	67	53	53	50	51	50	47	50	48	47
70	53	52	50	48	49	48	49	48	48	49
60	50	50	55	55	47	48	52	47	47	50
50	60	50	50	52	49	49	49	45	45	47
40	50	49	49	49	53	41	51	51	47	48
30	50	42	45	43	46	49	48	51	46	52
20	58	45	48	50	46	47	49	52	49	51
10	49	48	49	47	51	49	50	47	49	47

Figure 17: Changes in average user elapsed time per passenger when commuting to work for 3D elevator A-type

Top floor (F) \ Number of passengers (n)	10	20	30	40	50	60	70	80	90	100
100	20	11	8	7	6	5	5	5	5	4
90	15	9	7	6	5	5	5	4	4	4
80	15	8	7	5	5	5	5	4	4	4
70	13	7	7	5	5	4	4	4	4	4
60	12	7	6	4	5	4	4	3	4	3
50	9	5	5	4	4	4	3	3	3	3
40	7	4	4	3	4	3	3	3	3	3
30	5	3	4	3	3	3	3	3	3	3
20	3	3	3	3	3	2	3	2	3	2
10	3	2	2	2	2	2	2	2	2	2

Figure 19: Changes in average user elapsed time of high-speed elevator per passenger when commuting to work for 3D elevator B-type

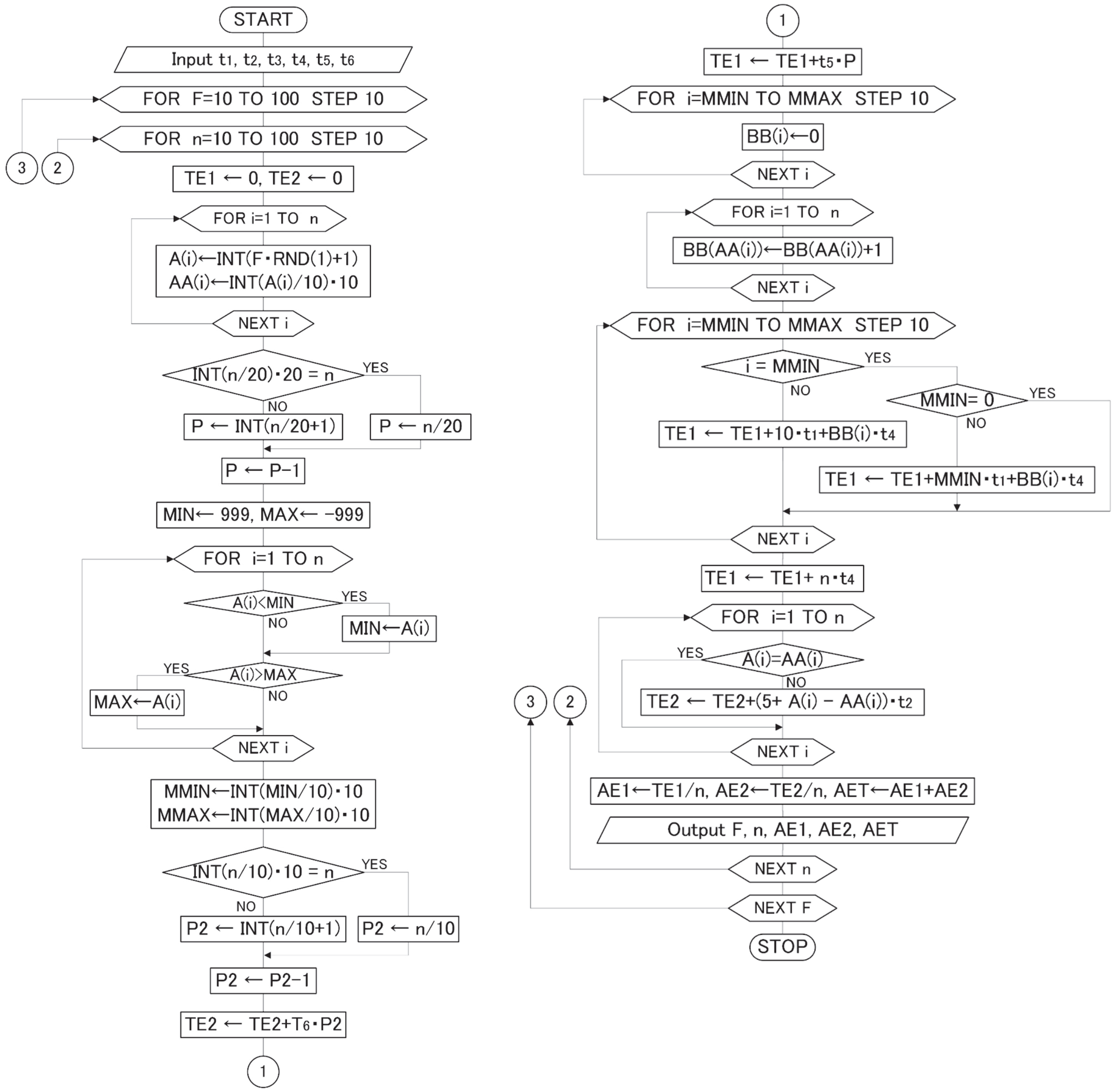

Figure 18: Flowchart for deriving the changes in average user elapsed time for 3D elevator B-type

Top floor (F) \ Number of passengers (n)	10	20	30	40	50	60	70	80	90	100
100	37	48	50	44	41	44	45	47	45	44
90	40	52	39	42	46	41	48	45	50	46
80	52	46	47	47	47	46	43	47	46	44
70	40	46	44	45	45	46	46	46	45	46
60	38	44	50	52	44	46	49	45	44	48
50	51	46	46	49	46	46	47	43	43	45
40	43	46	46	47	51	39	48	48	44	45
30	45	40	42	41	45	47	46	48	44	50
20	55	43	46	47	43	45	47	50	47	50
10	46	47	48	45	50	48	48	45	47	46

Figure 20: Changes in average user elapsed time of low-speed elevator per passenger when commuting to work for 3D elevator B-type

Top floor (F) \ Number of passengers (n)	10	20	30	40	50	60	70	80	90	100
100	57	59	58	51	47	49	50	52	50	48
90	55	61	46	48	51	46	53	49	54	50
80	67	54	54	52	52	51	48	51	50	48
70	53	53	51	50	50	50	50	50	49	50
60	50	51	56	56	49	50	53	48	48	51
50	60	51	51	53	50	50	50	46	46	48
40	50	50	50	50	55	42	51	51	47	48
30	50	43	46	44	48	50	49	51	47	53
20	58	46	49	50	46	47	50	52	50	52
10	49	49	50	47	52	50	50	47	49	48

Figure 21: Changes in average user elapsed time per passenger when commuting to work for 3D elevator B-type

time. In this paper, the characteristics of three types of elevators are as follows. The general high-rise building elevator system (G-type) is a conventional type elevator, consisting of high-speed elevators that stop only on the main floors and low-speed elevators that stop at each floor. The 3D elevator A-type consists of high-speed loop elevators that only stop on the main floors, and low-speed elevators that only stop between a limited number of floors. The 3D elevator B-type consists of high-speed loop elevators that only stop on the main floors, and low-speed loop elevators that only stop between a limited number of floors. In the G-type system, if there are too many passengers to fit into the electric box in high-speed elevators and low-speed elevators, the box has to return to the 1st floor many times until all passengers have been carried by the system. In the A-type, all passengers on the 1st floor can get into the high-speed elevator since the loop elevator system is used. However, the electric box has to return when all passengers cannot fit into the box in the low-speed elevators. In contrast, the passengers can reach the destination floor in one trip because the B-type is adopting the loop elevator system for high-speed and low-speed elevators. There are no passengers left behind in the elevator box.

The realization of a loop elevator using the 3D elevator is an extension of the double-deck elevator and overcomes its drawbacks. This is because the double-deck elevator consists of two electric boxes, but the system proposed in this study can connect any number of boxes. Also, the double-deck elevator system is wasteful when the number of passengers decreases, but the number of electric boxes can be reduced according to the number of passengers in the proposed system.

Furthermore, it became clear that A-type and B-type were more efficient than G-type when comparing the efficiency of these three types. Also, there is almost no difference in efficiency between A-type and B-type. Slightly better efficiency results were obtained for A-type. However, these differences are considered to be influenced by the values of $t_1, t_2, \ldots, t_6$.

The specific results in the tables can be considered as follows:

- In any table, it does not mean that the average user elapsed time increases just because the number of passengers *n* increases. As the number *n* of passengers increases, the total elapsed time increases. The average elapsed time is the total elapsed time divided by the *n*. Even if the *n* increases, the average elapsed time does not necessarily increase.
- The average user elapsed time tends to increase as the top floor F becomes higher in the high-speed elevator system. The number of floors that the electric box must stop on increases when F increases, and the elapsed time for each passenger to reach the destination floor increases. As a result, the average elapsed time is longer.
- The average user elapsed time of low-speed elevators for both A-type and B-type is almost the same, regardless of F or *n* although there is some variation. The reason for this is that the low-speed 3D elevator system moves within a limited range and it is not affected much by F and *n*, and the average elapsed time becomes almost the same.
- In the G-type low-speed elevator system, the average user elapsed time increases as F increases. The G-type low-speed elevator system may stop at all floors, and the larger the F, the more opportunities to move to higher floors. As a result, the average elapsed time increases.

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