System design and operational analysis of a three-dimensional urban mobility system for high-rise building clusters

Kazuya Okada (Graduate School of Science and Engineering, University of Toyama, okada.k153@gmail.com, Japan)
Haruhiko Kimura (Faculty of Transdisciplinary Sciences for Innovation, Kanazawa University, kimuraharuhiko05@gmail.com, Japan)
Takashi Oyabu (Nihonkai International Exchange Center, oyabu24@gmail.com, Japan)
Tadanobu Misawa (Graduate School of Science and Engineering, University of Toyama, misawa@eng.u-toyama.ac.jp, Japan)
Shigeki Hirobayashi (Graduate School of Science and Engineering, University of Toyama, hirobays@eng.u-toyama.ac.jp, Japan)

Abstract

The most novel aspect of this study is to clarify the advantages of a three-dimensional (3D) urban mobility system that connects clusters of high-rise buildings. It is necessary to develop a three-dimensional urban mobility system connecting high-rise buildings due to serious traffic congestion in cities. A three-dimensional taxi is proposed as an example in this paper. This taxi is expected to be an innovative alternative to ground transportation which is widely used. The purpose of this study is to clarify the advantages of this three-dimensional taxi. First, the basic model of this system is described. Next, the following basic functions (four functions) of this system will be introduced. (1) Vehicle dispatch management function for busy and off-peak times: Empty vehicles will be moved in advance to the areas where the congestion is expected and kept waiting. In addition, during times of off-peak (low demand), the 3D taxis will automatically move to a dedicated waiting space and reduce the power consumption for the entire system. (2) The 3D taxi-route determining function: The optimal 3D travel route is derived based on real-time demand responses and traffic conditions. (3) Safety management functions (including collision avoidance): It controls the safe and smooth passage of 3D taxis at intersections, etc. Furthermore, even on a straight path, when multiple 3D taxis are in the same vicinity, the control software is automatically implemented to avoid collisions. (4) Evacuation procedures in the event of a high-rise building fire: The 3D elevators can operate and 3D taxis can be also used even during a power outage. Specifically, the average waiting time required for dispatching 3D taxis is derived when they are placed at several stops in a 3D route network. Simulations are conducted to clarify how the average waiting time for dispatching taxis changes as the number of 3D taxis increases.

Key words
high-rise building clusters, 3D urban mobility system, average waiting time for dispatching, route determination, high rise building fire

1. Introduction

In recent years, the number of areas with high-rise buildings has increased as cities have become more densely populated. While these buildings make effective use of limited land space, they also create new challenges for people's mobility. In particular, human movement is becoming more complex both vertically (up and down) and horizontally (within and between buildings). Its efficiency affects the productivity of all urban activities. The dependence on elevators is extremely high in the vertical movement. Waiting times become longer and congestion becomes noticeable at peak times such as when arriving or leaving work and during lunch breaks. The elevators may stop during disasters, which makes it difficult to evacuate from upper floors, and safety concerns have also been raised. In horizontal movement, many buildings are designed independently, so when moving between buildings, it is necessary to go down to the ground floor first. There are structural constraints. In other words, the ground-level space is congested and it leads to inefficiencies such as pedestrians and vehicles intertwining. There is a challenge that the pathways are complicated inside the multi-use buildings and it becomes difficult to reach destinations. For the elderly and people with physical disabilities, moving up and down or traveling long distances in urban buildings can be physically burdensome, and it leads to disparities in accessibility. These challenges reduce the convenience, comfort, and safety of cities, and affect the development of sustainable transportation systems in urban areas where the population is expected to concentrate in the future. Therefore, it is necessary to understand people's movement in high-rise buildings three-dimensionally (vertically, horizontally, and in height) and to redesign an efficient and safe movement system (Al-Kodmany, 2015; Ding et al., 2019; 2021; Gravit et al., 2021; Ng, 2017). In this study, a '3D taxi connecting high-rise buildings' is proposed based on this background. This study aims to clarify the challenges related to human movement in clusters of high-rise buildings and to develop a new transportation system that contributes to their improvement.

The 'Proposal for a 3D Urban Mobility System (3D Taxi) Connecting Skyscrapers' is an innovative idea that effectively utilizes the 3D space of a city and revolutionizes the efficiency of moving people and goods. This concept has the potential to contribute to alleviating urban congestion, reducing travel time, and improving energy efficiency. The following items can be considered as potential applications.

- A transportation network connecting super high-rise buildings in a mega-city:
  For example, Shinjuku Subcenter, Marunouchi, Roppongi Hills areas, etc. will be connected in three dimensions.
- Connecting buildings such as hospitals, research institutes, and pharmaceutical companies:
  Medical-related logistics and personnel exchanges will be accelerated.
- Realizing a disaster response network:
  It will be connected to an adjacent building and used as an evacuation route in an emergency.

This system (3D elevator system) is equipped with these basic technologies (Kimura et al., 2024a; 2024b). The elevator can move not only up and down (vertically), but also left and right and forward and backward. If this elevator system is connected between multiple high-rise buildings, people and goods can be moved three-dimensionally and efficiently, without relying on ground-level or underground transportation as in the past. In this study, this 3D elevator is proposed as a 3D taxi. Below are the advantages of 3D taxis.

This proposal comes after years of work on improving the efficiency of vertical movement within high-rise buildings. The sky lobby system has been adopted in buildings (John Hancock Center, 2024; Toranomon Hills, 2024; Yokohama Landmark Tower, 2024) such as 'Abeno Harukas' (Abeno Harukas, 2024) as an efficient method of operating elevators in high-rise buildings (skyscrapers). In this system, the passengers transfer at specific floors (sky lobbies) (Sky Lobbies, 2024), ensuring transport capacity and shortening travel times. There is also a double-deck elevator system (Double Deck Elevator, 2023), which increases transport capacity by 1.5 to 1.9 times by connecting the elevator cars (*kago* in Japanese) top and bottom, and it also contributes to reducing installation space. This system has been introduced in Azabudai Hills Mori JP Tower (Azabudai Hills Mori JP Tower, 2024) and other buildings. The authors of this paper have previously conducted research on a 3D elevator system that can efficiently operate elevators for super-high-rise buildings (Kimura et al., 2024a; 2024b). The research applies the space utilization technology for a multi-story parking lot. This system had some limitations that needed to be addressed. The sky lobby system has the problem that the available space will decrease and space costs will increase if more sky lobbies are built to reduce travel time. The double-deck elevator system also has a structural inefficiency. In other words, two elevator cars are being operated even when there are few passengers. These methods alone are insufficient for efficiently operating elevators in super high-rise buildings. Previous research on elevator systems has focused on the efficient operation of the individual super-high rise building's elevators. A vehicle which can move between connected high-rise buildings (skyscrapers) has not yet been invented. Like the ordinary ground transportation, the challenge is to develop a new transportation system that allows comprehensive movement through 3D space of the city (Gravit et al., 2021).

In this study, a '3D taxi' that can move between connected high-rise buildings, based on the 3D elevator model is proposed. It is a paid electric box car dedicated to individuals or a small number of passengers who want to move within a cluster of high-rise buildings. It can move freely within three-dimensional space using traffic signals (sensors) installed along pathways. This system achieves flexibility and efficiency that could not be realized with conventional transportation systems. In other words, it has the following three functions. First, it can be moved near to an area expected to be crowded in advance and positioned as an empty one. It is automatically moved to the waiting area during off-peak hours. This allows the overall system efficiency and power consumption to be controlled. Second, it can calculate the route that can be reached in the shortest time (optimal 3D movement route) based on real-time demand and traffic conditions (route determination function). Thirdly, this taxi is equipped with collision avoidance and safety management functions to ensure safe and smooth passage through intersections and along straight pathways. In this study, the superiority of this system is demonstrated through simulations and analyses. Additionally, it establishes the concrete design guidelines and the feasibility of introducing a three-dimensional traffic system in future urban planning.

2. Basic model of the system

2.1 3D taxi moving through a cluster of high-rise buildings

In this section, the 3D taxi that can move around high-rise buildings (skyscrapers) in all directions (left-right, front-back, up-down) is proposed. The 3D taxi has no driver and can continue operating even during a power outage. Under normal conditions, it runs on electricity; however, in the event of disasters (such as earthquakes or fires), it becomes a self-contained vehicle powered by a diesel engine. Two 3D taxi lanes (one for ascending and one for descending) are installed everywhere in the cluster of high-rise buildings. The taxi can move left and right, forward and backward, up and down using traffic lights (equipped with sensor functions) just like on regular roads at each intersection. The 3D taxi stands are located at major gathering spots within high-rise buildings or at locations set up based on customer requests (it is not free). There are two ways to call the taxi using a mobile phone or by calling out at a taxi stand. The destination is set by voice, and payment is made using a dedicated IC card or commonly used electronic money or credit cards.

Next, the 3D taxi system is explained. The 3D taxi has a square shape, as shown in Figure 1. There are four doors for getting on and off, but only the side door for passengers to pass through opens. There are a few seats set up inside. The 3D taxi movements (left-right, forward-backward, up-down) are carried out using multiple electric gears installed on the left-right sides of the taxi, the forward-backward sides, and the four corners arranged diagonally. Specifically, when moving sideways, only the electric gears on the left and right sides are used, while the electric gears on the front and back sides and those installed at the four corners are stored within the taxi body. Other movements are performed in the same way. In addition, the corners of the taxi have been flattened to allow the electric gear to shift out from the four corners.

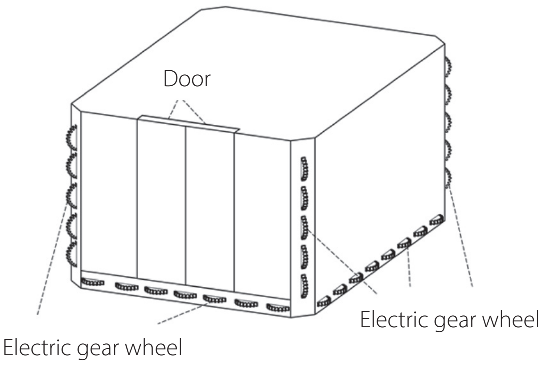

Figure 1: 3D taxi

Funase et al. (Funase et al., 2022) proposed a 3D parking lot that makes maximum use of the space. Kimura et al. (2024a; 2024b) applied this result and proposed a 3D elevator system. The 3D elevator system is made up of a skeleton of poles like a jungle gym. It is shown in Figure 2. The electric box can move left and right, up and down, and back and forth inside this. The box inside the system is indicated in Figure 3.

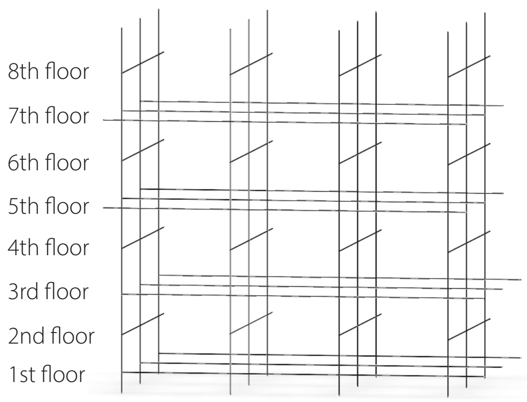

Figure 2: Skeleton diagram of a 3D elevator (three places on the left and right, eight places on the top and bottom, two places at the front and back)
Source: Funase et al. (2022).

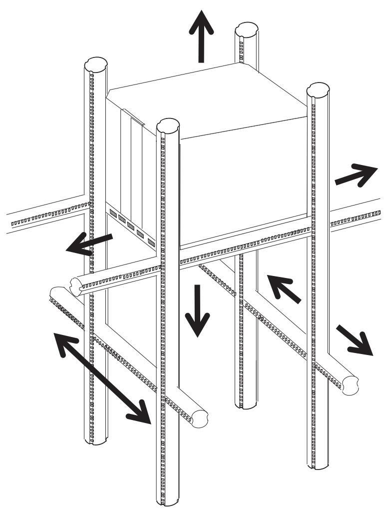

Figure 3: Electric box inside the 3D elevator system

The electric box used inside the 3D elevator and the 3D taxi have the same external appearance; however, the electric box does not have seats. The electric box is primarily designed for vertical movement, functioning as an elevator that can additionally move forward, backward, and sideways as needed. Compared to the 3D taxi, it is a short-distance transportation mode that enables quicker travel over brief periods. In contrast, the 3D taxi is intended for medium- to long-distance travel and is therefore equipped with seats. It can rather be regarded as a vehicle that moves in three dimensions.

When the box moves in the left and right directions, it must be on an odd-numbered floor. The electric gears on the left and right sides of the box only extend, and the other gears inside the box retract. The state in which the grooves of the gear and the horizontal pole fit together is shown in Figure 4. This figure is the cross-sectional view from above.

When the gear passes through the vertical pole, it is pushed up, and it returns to its original position by a spring after passing, allowing the gear and the horizontal pole to

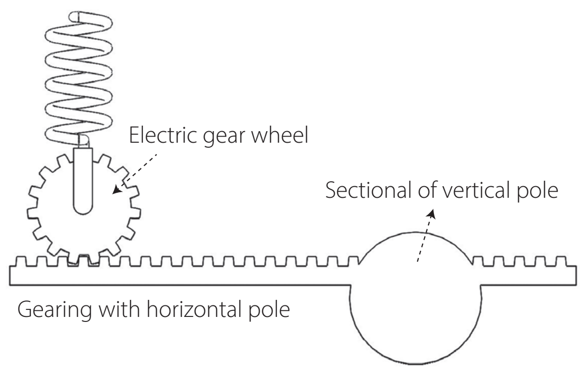

Figure 4: Fitting condition of the electric gear and the groove of the horizontal pole (cross-sectional view from above)
Source: Funase et al. (2022).

fit together (the bumps fit together). The gear moving along the vertical pole is pushed upward by the driving force of the other gears fitted with the horizontal pole.

When the box moves up or down, it is moved to a position where its four corners are directly in front of the vertical poles. At that time, the electric gears on the left and right sides and on the front and rear sides are retracted. Then, the gears from the four corners are extended and fitted them into the grooves of each vertical pole. This process allows for vertical movement of the box. Also, the way the electric gears coming out of the corners fits into the vertical pole is the same as the way the horizontal pole and electric gear move left and right. There are no poles to get in the way when moving.

When the electric box moves forward or backward, it must be on an even-numbered floor. The electric gears on the left and right side-surfaces and the gears from the four corners are retracted, and only the ones on the front and rear side surfaces are extended and fitted into the grooves of the front and rear poles. When passing through the vertical pole, the same process occurs as when moving left and right, and a spring pushes up the electric gear. This process allows the box to move forward and backward.

The switching movement from the other direction is performed as follows. The 3D elevator shown in Figure 2 can move left and right and up and down on the first floor, but cannot move forward and backward as it is. Also, it can move forward and backward and up and down on the second floor, but it cannot move left and right directly. It is necessary to go up or down an odd number of floors in the vertical direction firstly to perform such movements that cannot be performed directly. In the 3D elevator shown in Figure 2, the odd-numbered floors are the same as the first floor, and the even-numbered floors are the same as the second floor. Also, it cannot move forward or backward on the first floor because the front and rear horizontal poles block the forward or backward movement of the electric box. And this is also because there is not a pair of horizontal poles in the front-to-rear direction that serve as rails for movement. Similarly, left and right movement is not possible on the second floor because the left and right horizontal poles block the left and right movement of the box, and there is not a pair of left and right horizontal poles to serve as rails for movement. This means that the electric box can move freely left and right, up and down, and forward and backward as the 3D elevator. The 3D taxi is a paid electric box for personal use that moves around within high-rise buildings.

2.2 Traffic control for 3D taxis

The 3D taxi is self-driving and it will stop at the places where people gather or at contracted locations (stops). The taxi can be called to the nearest stop using a voice device at the stop or a mobile phone. A passenger can also specify the time and make a reservation. The passageway (corresponding to a road) through which the taxi travels usually has at least one rail going up and one going down. The traffic lights (with image sensors etc.) are placed at intersections where the taxi can move left and right, forward and backward, and up and down. A taxi is called by a customer at the nearest stop and travels to the destination stop. The route to a designated stop is understood as a series of a branching point group. The 3D taxi is a vehicle that travels through a 3D network. The typical vehicular traffic network is controlled by 2D branching traffic lights. The vehicle proposed in this study is realized in three dimensions. The 3D taxis can only be called from specific locations that correspond to registered stops. A passenger can either call a taxi using the microphones installed at each stop or by requesting with a cell phone. When a taxi call request is received, the nearest taxi that is on standby will handle it. The destination is identified through voice recognition, and information about the series of waypoints to be passed from the departure point to the destination is derived. The taxi will be guided to the destination based on that information. This process is shown in Figure 5. When the passage is crowded, the travel time for each route to the destination is predicted, and the route with the shortest time is chosen.

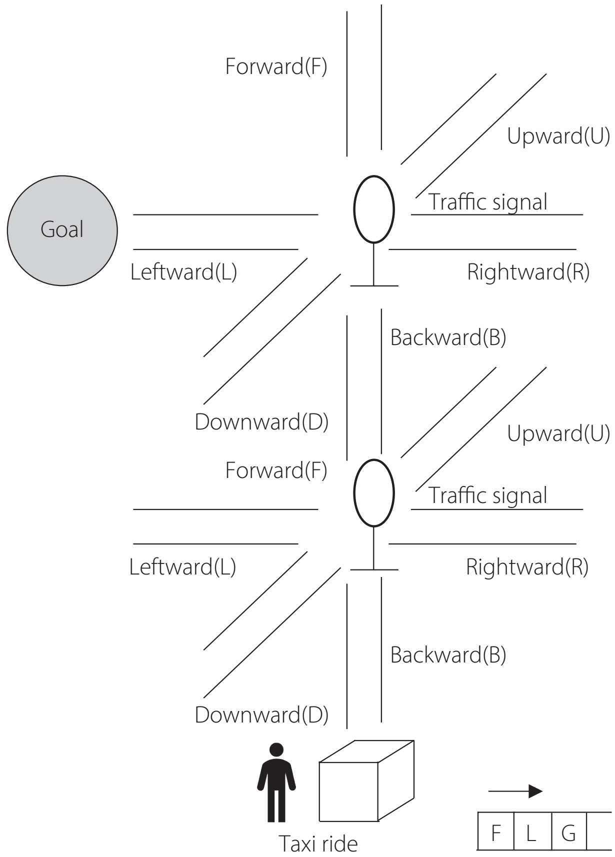

Figure 5: Directions to the destination

3. Main functions of the system

This study assumes the advanced traffic control functions that support the operation of a 3D taxi moving vertically and horizontally among high-rise buildings. This control system aims to achieve integrated management of the three-dimensional passage network, improve the efficiency of movement, and ensure safety. These objectives were difficult to achieve with conventional vertical elevator systems.

3.1 Taxi dispatch management function for busy and off-peak times

This feature is designed to proactively respond to system demands, minimize customer-wait times, and optimize the overall power consumption of the system. This system is different from the conventional one which responds passively after demand arises, and it can optimize the allocation of a taxi with no passengers based on demand forecasts. The empty taxis (electric taxis) are pre-emptively moved and stationed near areas where congestion is likely to occur as a measure to control congestion based on past operation data and real-time demand fluctuations. If congestion is expected in certain area or time periods, the system will follow the predictive algorithms to have some taxis standby in advance. For example, the rush of people leaving at the end of office hours can be predicted and the request of the passenger is responded to by concentrating empty taxis near the connecting passages between buildings and major floor stops before demand increases. This will significantly reduce waiting times during peak periods and help avoid sudden spikes in network load. On the other hand, the purpose of controlling during off-peak times, such as late at night or on holidays when demand is low, is to prioritize the reduction of energy consumption. During off-peak times, the system automatically moves the 3D taxis in operation to designated standby spaces that do not affect the operation of the passageways. It reduces the power consumption when the empty taxis drive unnecessarily on the passageway network or wait on each floor, thereby improving the overall power efficiency of the system.

3.2 Route determination function

This function dynamically creates the optimal route (dynamically deriving the shortest time) for passengers to reach their destination on a three-dimensional route (passageway) network. It is necessary to understand the status of all routes in real time, similar to signal control in two-dimensional traffic networks, because the 3D taxi routes have complex branching paths. When a passenger takes the taxi and sets their destination using voice recognition, the control system is activated. The routing algorithm does not simply choose the shortest distance. It comprehensively understands all factors in real time, such as congestion levels, operation status of other electric boxes, and delay prediction due to switching between odd and even floors. Based on this understanding, it predicts the required travel time for each route. As a result, congestion is avoided even if the distance is somewhat longer, and the three-dimensional route that can be reached in the shortest time is dynamically selected. It also prevents the load from concentrating on specific routes on the network, and maintains the smooth movement.

3.3 Collision avoidance and safety management functions

The purpose of this function is to avoid collisions between the electric boxes and ensure the safety of passengers in the complex environment of a three-dimensional passageway network. A sensing system which corresponds to a traffic light is installed in the passway where the 3D taxi travels. It also accurately monitors the position and speed of every box. In particular, at three-dimensional intersections where traffic intersects from multiple directions (up and down, left and right, front and back), the system determines the priority of each box. If there is a risk of collision, the system will instruct one of the boxes to temporarily stop or adjust its speed. These functions enable safe and smooth traffic control at three-dimensional intersections. When multiple boxes enter each other's safety zones on a straight passway, the system intervenes and automatically gives instructions (deceleration control etc.) to maintain a safe distance from the box ahead. This multiple safety control is achieved by a sensor system (operating at all times) and ensures the safe operation of the entire system.

3.4 High-rise building fire evacuation procedures

The system will be able to operate even during power outages by utilizing the operational 3D elevator boxes and 3D taxis, and will attempt a safe escape using AI-based route selection. Non-flammable materials will be used for the passageways.

4. Simulation of average waiting time for dispatching 3D taxi

First, the total number of stops n is determined, and a table is created to calculate the travel time tij between any two stops S_i and S_j. Here, $t_{ij} = t_{ji}$. Next, m stops S_1*, S_2*, . . ., S_m*, where one 3D taxi will be placed in advance, are randomly determined. Furthermore, the candidate stops for calling a 3D taxi (destination stops) are whole stops, and those are selected randomly. The 3D taxi that responds to the request will use the one parking at the stop closest to the destination stop. It supposes that once the 3D taxi arrives at the destination stop S_e, it will wait there until it is requested again. In other words, if a 3D taxi dispatched to Se leaves from S_r*, then S_r* ← S_e. As a result, if the dispatch continues, there is a high possibility that duplicating stop numbers will appear in S_1*,

$S_2^*, \ldots, S_m^*$.

4.1 Experiment 1

The total number of stops n in the 3D passageway is determined, and the total travel time between the stops for the 3D taxi using uniform random numbers is generated. The relationships between them are shown in Table 1. Next, the stops $S_1^*, S_1^*, \ldots, S_m^*$ where the 3D taxis will be placed in advance are determined using uniform random numbers.

The destination taxi-stop (where the 3D taxi will be dispatched) is selected using a uniform random number. The stop from which the 3D taxi will be dispatched is determined from Table 1, and the waiting time required for dispatch is calculated. This process is repeated *k* times to calculate the average waiting time for dispatching the taxi.

Here, the following steps (operations) are performed *h* times:

"Repeat *k* times to find the average waiting time for dispatching a taxi"

In other words, the "average waiting time for dispatching a 3D taxi" can be calculated from the waiting times for dispatching a taxi from the *1*st to the *k*th. The second "average waiting time required for dispatching a taxi" is calculated from the waiting times required for dispatching a taxi from the *k* + *1*st to *2k*th vehicle. Similarly, the same processes are repeated to find the *h*-th "average waiting time required for dispatching a taxi."

4.2 Results

The average waiting time required for dispatching 3D taxis when they are placed at several stops in the 3D route network, is calculated. The flowchart for deriving the result is shown in Figure 6. Three cases are shown in Tables 2 to 4 as specific examples of the results. Here, the values of *n*, *k*, and *h* are all set to 10, and the value of m is changed to 3, 5, and 7. In Table 2 (m = 3), the minimum value is 1.1, the average value is 1.97, and the maximum value is 3.2. In Table 3 (m = 5), the minimum value is 0.4, the average value is 0.96, and the maximum value is 1.6. In Table 4 (m = 7), the minimum value

Table 1: The 3D taxi travel time t_{ij} from stop xi to stop x_j

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
X1	0	4	8	8	7	2	7	9	7	2
X2	4	0	9	8	6	2	8	4	1	10
X3	8	9	0	4	9	4	2	2	8	7
X4	8	8	4	0	8	4	10	6	1	10
X5	7	6	9	8	0	6	7	10	10	4
X6	2	2	4	4	6	0	1	10	4	10
X7	7	8	2	10	7	1	0	9	4	1
X8	9	4	2	6	10	10	9	0	8	2
X9	7	1	8	1	10	4	4	8	0	9
X10	2	10	7	10	4	10	1	2	9	0

Table 2: Results of Experiment 1 (m = 3, h = 10)

i	*i*-th "average waiting time for dispatch (minutes)"
1	2.1
2	1.4
3	1.1
4	2.1
5	1.7
6	1.1
7	2.1
8	2.7
9	3.2
10	2.2

Table 3: Results of Experiment 1 (m = 5, h = 10)

i	*i*-th "average waiting time for dispatch (minutes)"
1	0.7
2	1.2
3	0.4
4	0.9
5	1.0
6	1.6
7	1.2
8	0.7
9	0.7
10	1.2

Table 4 Results of Experiment 1 (m = 7, h = 10)

i	*i*-th "average waiting time for dispatch (minutes)"
1	0.4
2	0.7
3	0.1
4	0.4
5	1.3
6	0.4
7	0.2
8	0.7
9	0.6
10	0.6

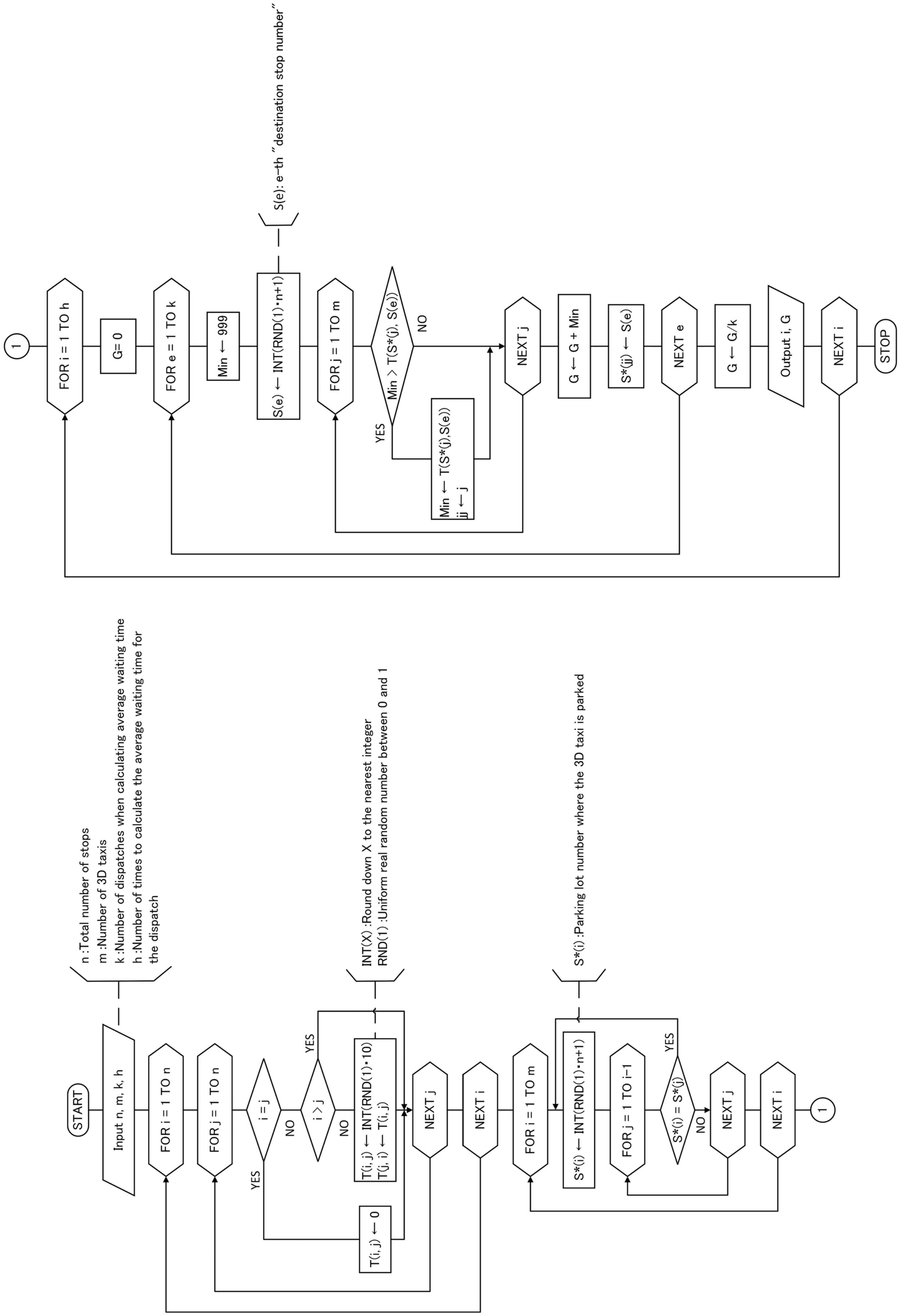

Figure 6: Flowchart for finding the results of Experiment 1

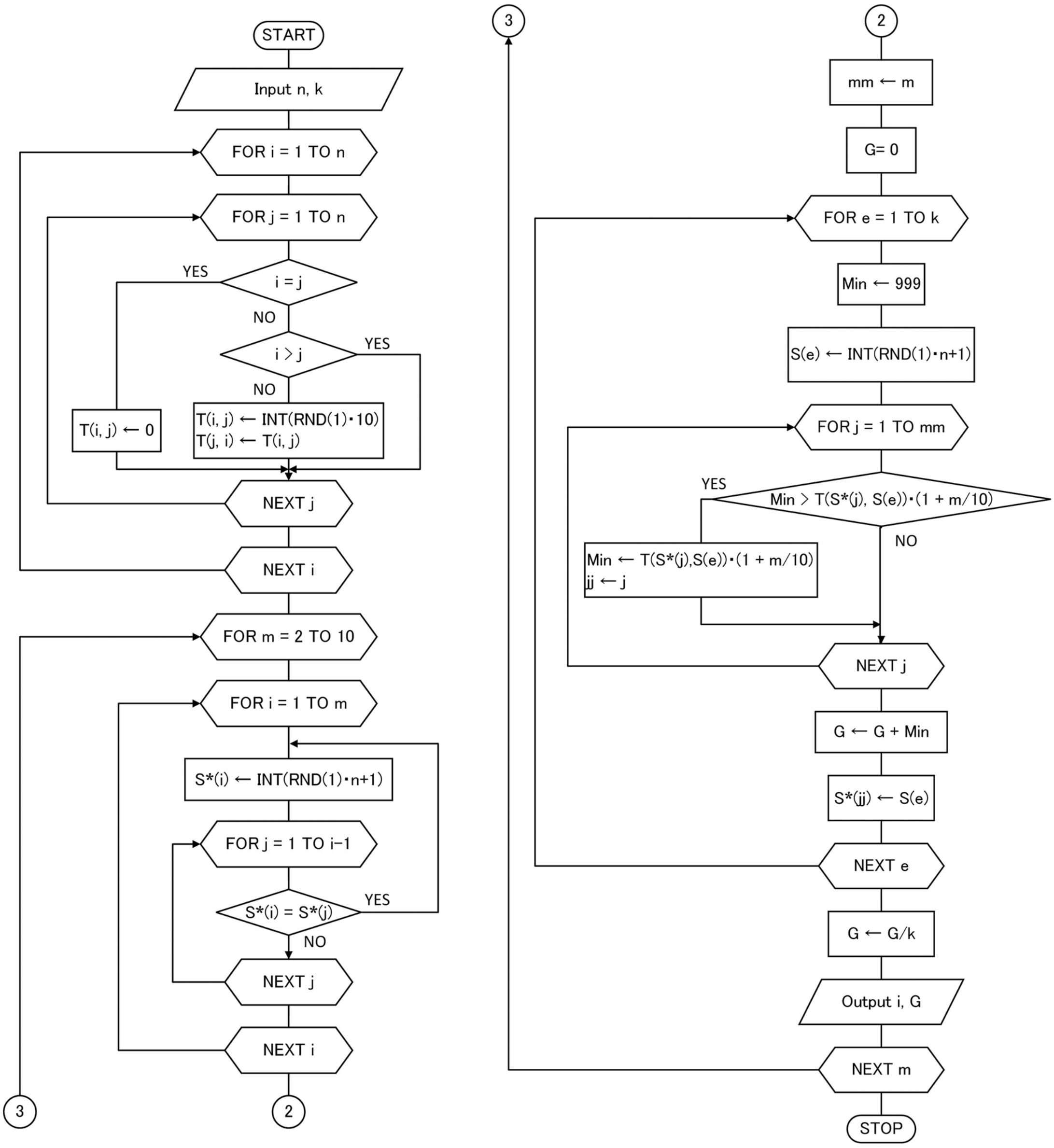

Figure 7: Flowchart for deriving the results of the Experiment 2

is 0.2, the average value is 0.54, and the maximum value is 1.3. The average waiting time for dispatching a taxi will definitely decrease as the number of 3D taxis increases. This is a trend that cannot be understood without actually simulating it.

4.2 Experiment 2

Simulations were used to find how the average waiting time for dispatching a 3D taxi changes as m increases. However, as the number of 3D taxis increases, the passageways become more congested, and the average waiting time for dispatching the taxi becomes longer. Therefore, let $t_{ij} \leftarrow t_{ij} \cdot f(m)$.

4.3 Results

The flowchart for deriving the results of Experiment 2 is shown in Figure 7. The results when $f(m) = 1 + m / 10$ are indicated in Table 5. The values of each parameter are $n = 10$, $m = 2$ to 10, and $k = 10$. As expected, the average time required to dispatch the taxi decreases as the number of 3D taxis increases. When $m = 10$, the waiting time is 0. This result means that the 3D taxis are waiting at all stops. The waiting time for dispatch is zero. According to this experiment, it is possible to obtain the specific average waiting time required for dispatching the taxi through simulation.

5. Conclusion

This paper is about the application of a 3D elevator system that connects high-rise buildings. It includes the following two studies:

- A 3D elevator system that efficiently operates a single elevator for super high-rise buildings.

Table 5: Results of the Experiment 2

Number of 3D taxis	Average waiting time (minutes)
2	3.024
3	2.002
4	1.75
5	1.485
6	0.88
7	0.731
8	0.414
9	0.209
10	0

- A 3D taxi that travels between major locations in a group of connected high-rise buildings.

This paper makes a basic proposal for the latter study because there are the published papers on the former one (Kimura, 2024a; 2024b).

The specific four functions of this system are as follows: (1) Dispatch management function of a 3D taxi for busy and quiet times: the empty 3D taxis will be moved in advance to areas where congestion is expected and kept waiting. During times of low demand (off-peak times), the 3D taxis will automatically move to a dedicated waiting space to reduce power consumption for the entire system. (2) Route determination function: the system calculates an optimal 3D travel route based on real-time demand and traffic conditions. (3) Collision avoidance and safety management functions: the system controls the 3D taxi to pass through intersections safely and smoothly. Even on a straight pathway, a control function automatically intervenes to avoid collisions when multiple 3D taxis enter the same vicinity. (4) High-rise building fire escape procedures: the use of 3D elevators and 3D taxis that can operate even during power outages were considered. In order to establish specific design guidelines and the validity of introducing a 3D transportation system in future urban planning, simulations to clarify how the average waiting time required for dispatching the 3D taxis change as the number of 3D taxis increases, was conducted.

The following are some of the expected outcomes of this study:

- Decreasing urban congestion:
  Reducing ground traffic.
- Improving barrier-free mobility:
  Elderly people and people with disabilities will be able to move around the city stress-freely.
- Affinity with smart city concepts:
  Easier to control the entire urban space in an integrated manner.
- Building integration and shared functionality:
  Ease of linking facilities and services across multiple buildings (hospitals, commercial facilities, public services, etc.).
- Safety and disaster response:
  Under normal conditions, safety is enhanced through multilayer redundant design, 3D city models combined with AI-based control, and a hybrid approach integrating autonomous and remote operations. In disaster situations, safety can be ensured through distributed and autonomous infrastructure, real-time system reconfiguration, and functionality as a rescue and logistics platform.

In addition, the following issues can be considered:

- Establishment of Building Standards Act and urban planning:
  Legal compliance must be ensured so that buildings can be connected.
- Security and privacy guaranteed:
  There is a need for access control in movements between buildings.
- Introduction cost and maintenance management:
  The challenges related to introduction costs include increased initial construction costs, the difficulty of retrofitting existing buildings, system integration costs, and uncertainty in business profitability. In addition, challenges related to maintenance and management include the increasing sophistication and complexity of inspection and maintenance, expansion of the impact range in the event of failures, disaster response costs, growth of lifecycle costs, and complexity of operational management.
- Consensus among building owners:
  Agreement is required for each building owner.
- The relationship with the Building Standards Act and the City Planning Act:
  3D urban mobility systems for high-rise building clusters constitute a new type of infrastructure positioned at the boundary between the Building Standards Act and the City Planning Act. Therefore, it is necessary to propose integrated design guidelines that combine building and urban planning regulations, as well as to develop a new legal framework adapted to 3D urban spaces.

In addition, there are other important issues not addressed in this study, which should be considered as future challenges. These include the following:

- Redundant system design:
  Since a failure at a single point can have a significant cascading impact on the entire urban system, fail-safe and fail-operational mechanisms are required.

- Cybersecurity:
  Infrastructure hacking can directly lead to serious accidents.

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