Abstract: This study proposes a method of location planning of elevators based on passengers’ physical and conscious resistances. And this study clarifies the optimum and maximum distances of an elevator from traffic lines of passengers as the elevator’s location will be acceptable, especially for the elderly. To analyze the distance on basis of physical resistances, this study applied the transfer resistance model which was improved by the Japan Railway Construction Public Corporation. Using this model, we analyzed the effects of reducing physical resistance to elevators comparing with stairs at main 10 subway stations in Sapporo. Kishi’s Logit PSM (KLP) was used for the analysis of conscious resistance.

Key Words: Location of elevator, Physical resistance, Conscious Resistance, KLP

1. INTRODUCTION

In Japan, the Barrier-free Transportation Law was established in November 2000, which has progressed convenience and safety of elderly and disabled people. The law regulates that vertical interval between the ticket gate and the platform at a public transport station should be dissolved by installation of elevators and slopes. Passengers, especially elderly or disabled people want to transfer through the shortest path by elevator or escalator without using the upstairs. Although locations of elevators or escalators at many stations have been improved, the standard concerning where they should be actually placed is not specified in the law. Therefore, some elevators are still installed far from passengers’ traffic lines and it forces people to detour. On the other hand, it is difficult for transportation administrators to install elevators near a main passenger traffic line because of limited space and budgets. Thus, how to install elevators as near as possible to the passengers’ permissible traffic zone comes to be an issue.
This study proposes guidelines for appropriate elevator locations at a station. This study evaluated elevator locations considering transfer from subway to bus by using kinetic energy consumption taking up Sapporo City subway as a subject. The study also showed standards for elevator location by taking into consideration passengers’ conscious resistance to use elevator.

In terms of public transportation transfer, the Japan Railway Construction Public Corp. developed transfer resistance formula from kinetic energy consumption, and it enabled to evaluate the transfer resistance quantitatively\(^1\). It evaluated transfer in the metropolitan area, and proposed positive introduction of high-speed elevators and escalators\(^2\). However, it is not possible to express the passengers’ conscious resistance only by the energy consumption. On the other hand, Iida \textit{et al.} evaluated passengers’ conscious burden for using upstairs and downstairs in transfer by generalization time\(^3\), but they have not clarified where elevator should be located. Kin \textit{et al.} made indexes of passengers’ tolerance of a distance to escalators in relation to the distance to stairs, and to passengers’ satisfaction with the location of escalators in the pedestrian deck\(^4\).

This study clarified that the installation of elevators is more important than that of escalators through a questionnaire survey, and proposed proper standards for elevator location considering passengers’ physical and consciousness resistance. The physical resistance applied transfer resistance formula developed by the Japan Railway Construction Public Corp., and we evaluated effects of elevator installation at main 10 Sapporo subway stations with a bus terminal. In the case of conscious resistance, Kishi’s Logit PSM (KLP) that has been applied for price evaluation, was applied for evaluation of the conscious distance resistance. The experiment was carried out targeting elderly people, and their consciousness such as “the elevator is far” and “it is near” to their traffic line was clarified.

2. QUESTIONNAIRE SURVEY ON ESCALATOR AND ELEVATOR USE

2.1 OUTLINE OF THE QUESTIONNAIRE SURVEY

A questionnaire survey was carried out in Sapporo from January 10\textsuperscript{th} to 13\textsuperscript{th}, 2001. As a result, 194 survey forms were collected. Respondents are classified into three groups; elderly people over 65 years old, middle-aged people from 30 to 64 years old and students in the 20’s. The number of respondents by group is 100 for the elderly, 39 for the middle-aged and 55 for students.

2.2 STATUS OF ESCALATOR AND ELEVATOR USE

In the questionnaire, we asked the respondents which they usually used, escalator or elevator (Figure 1). We have found that many people use escalators in every group.

Next, we asked whether they would feel a danger when they used stairs and escalator. For the elderly and middle-aged, the majority feels a danger when they go down stairs including the answer ‘both’ (Figure 2). This conscious burden is reduced by using escalator (Figure 3). It means that use of escalator is effective to reduce not only physical but also conscious resistance.
2.3 NECESSITY OF ELEVATOR LOCATION PLANNING

An Escalator is more contributive to reduction of conscious burden compared with stairs, but 50% people feel a danger when they use escalator. If they use elevator, they do not feel a danger at all and using elevator is effective for reduction of kinetic energy consumption. However, enough number of elevators are not installed or existing elevators’ locations are inconvenient. It is necessary to plan elevator location considering passengers’ conscious resistance.

3. ANALYSIS OF PHYSICAL RESISTANCE ON TRANSFER AT SAPPORO MUNICIPAL SUBWAY STATIONS

3.1 TRANSFER RESISTANCE BASED ON KINETIC ENERGY CONSUMPTION

As the method evaluating transfer from the viewpoint of kinetic energy consumption, the Japan Railway Construction Public Corp. has defined the equation that calculates transfer resistance (1). This equation calculates the amount of kinetic energy consumption by the relative metabolic rate in the field of labor science, and converts it into corresponding horizontal distance. 

![Figure 1](image1.png) "Which do you usually use, escalator or elevator?"

![Figure 2](image2.png) "Do you feel a danger when using stairs?"

![Figure 3](image3.png) "Do you feel a danger when using escalator?"
\[ E = X_1 + 0.636X_2 + 1.418N_1 + 0.831N_2 + 0.564N_3 + 0.424N_4 + 0.291N_5 \]  

(1)

where

- \( E \): transfer resistance (m)
- \( X_1 \): horizontal movement distance (m)
- \( X_2 \): horizontal distance of the moving sidewalk (m)
- \( N_1 \): the number of stairs to go up
- \( N_2 \): the number of stairs to go down
- \( N_3 \): the number of stairs of an escalator
- \( N_4 \): the number of stairs of a hi-speed escalator
- \( N_5 \): elevator (converted height into the equivalent number of stairs)

### 3.2 PHYSICAL TRANSFER RESISTANCE AT SAPPORO CITY SUBWAY STATIONS

We calculated the transfer resistance by Equation (1) at 10 Sapporo subway stations. The subject route was from the center of the platform to the bus terminal at each station. We surveyed horizontal movement and vertical distance of the shortest route in individual cases of using stairs, escalators and of elevators. We actually counted the number of stairs at each station.

The transfer resistance of each station is ranked in ascending order (Table 1). But Makomanai Station is excluded from the ranking because it is on the surface, and ticket gates and the bus terminal are on the same floor.

**Table 1  Physical transfer resistance at Sapporo city subway stations**

<table>
<thead>
<tr>
<th>Name of the station</th>
<th>Stairs Transfer resistance (m)</th>
<th>Escalator Transfer resistance (m)</th>
<th>Elevator Transfer resistance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kotoh 240.1</td>
<td>Kotoh 176.9</td>
<td>Kanjodori-Higashi 159.4</td>
<td></td>
</tr>
<tr>
<td>Kanjodori-Higashi 267.2</td>
<td>Shin-Sapporo 187.7</td>
<td>Sakae-machi 187.4</td>
<td></td>
</tr>
<tr>
<td>Kita 24 jo 268.8</td>
<td>Kanjodori-Higashi 209.1</td>
<td>Shin-Sapporo 193.5</td>
<td></td>
</tr>
<tr>
<td>Shin-Sapporo 275.7</td>
<td>Oyachi 265.1</td>
<td>Kotoh 207.4</td>
<td></td>
</tr>
<tr>
<td>Oyachi 319.2</td>
<td>Sakae-machi 278.3</td>
<td>Oyachi 224.1</td>
<td></td>
</tr>
<tr>
<td>Sakae-machi 348.3</td>
<td>Miyanosawa 315.0</td>
<td>Kita 24 jo 256.0</td>
<td></td>
</tr>
<tr>
<td>Asabu 353.5</td>
<td>Asabu 327.9</td>
<td>Miyanosawa 290.8</td>
<td></td>
</tr>
<tr>
<td>Fukuzumi 442.6</td>
<td>Fukuzumi 336.8</td>
<td>Fukuzumi 343.7</td>
<td></td>
</tr>
<tr>
<td>Miyanosawa 449.6</td>
<td>Kita 24 jo</td>
<td>- Asabu -</td>
<td></td>
</tr>
<tr>
<td>Makomanai 139.5</td>
<td>Makomanai 97.7</td>
<td>Makomanai 60.6</td>
<td></td>
</tr>
</tbody>
</table>

### 3.3 INSTALLATION EFFECT OF ESCALATORS AND ELEVATORS

From Table 1, we analyzed effects of escalator and elevator installation. We defined “the reduction rate of resistance” and “the installation rate” as Equation (2) and (3).

“The reduction rate of resistance”=1-(Transfer resistance with escalator and elevator/Transfer resistance without escalator and elevator)  

(2)
“The installation rate”=(The number of stairs covered with escalator and elevator/ 
\[ \text{The total number of stairs} \] \hspace{1cm} (3) 

The reduction rate of resistance shows how physical resistance is reduced by using escalators and elevators compared with the case by using stairs. The installation rate is a movable rate without using stairs from the platform to bus terminal. The results of calculation are on Table 2.

Table 2  Reduction rates of resistance and escalator and elevator installation rates

<table>
<thead>
<tr>
<th>Name of the station</th>
<th>Escalator Installation rate</th>
<th>Escalator Reduction rate of resistance</th>
<th>Elevator Installation rate</th>
<th>Elevator Reduction rate of resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shin-Sapporo</td>
<td>100%</td>
<td>31.9%</td>
<td>Makomanai</td>
<td>100%</td>
</tr>
<tr>
<td>Makomanai</td>
<td>100%</td>
<td>30.0%</td>
<td>Sakae-machi</td>
<td>100%</td>
</tr>
<tr>
<td>Miyanosawa</td>
<td>100%</td>
<td>29.9%</td>
<td>Kanjordori-Higashi</td>
<td>100%</td>
</tr>
<tr>
<td>Kotonni</td>
<td>100%</td>
<td>26.3%</td>
<td>Miyanosawa</td>
<td>55%</td>
</tr>
<tr>
<td>Fukuzumi</td>
<td>100%</td>
<td>23.9%</td>
<td>Shin-Sapporo</td>
<td>29%</td>
</tr>
<tr>
<td>Kanjordori-Higashi</td>
<td>60%</td>
<td>21.7%</td>
<td>Oyachi</td>
<td>28%</td>
</tr>
<tr>
<td>Sakae-machi</td>
<td>67%</td>
<td>20.1%</td>
<td>Fukuzumi</td>
<td>23%</td>
</tr>
<tr>
<td>Oyachi</td>
<td>100%</td>
<td>17.0%</td>
<td>Kotonni</td>
<td>100%</td>
</tr>
<tr>
<td>Asabu</td>
<td>34%</td>
<td>7.2%</td>
<td>Kita 24 jo</td>
<td>40%</td>
</tr>
<tr>
<td>Kita 24 jo</td>
<td>0%</td>
<td>0%</td>
<td>Asabu</td>
<td>0%</td>
</tr>
</tbody>
</table>

As for escalator, though the installation rate of Oyachi Station is 100%, the resistance reduction rate is small. As for elevator, though the installation of Kotonni Station is 100%, the resistance reduction rate is also small. That is because when people use escalators or elevators at these stations, they have to make a long detour. At Fukuzumi and Kotonni Station, the resistance reduction rate of escalator is higher than that of elevator because of far locations of elevators at these stations.

It became clear that the installation effect of escalators and elevators is different depending on their locations.

4. EVALUATION OF CONSCIOUS DISTANCE RESISTANCE TO ELEVATOR

4.1 THE CONSCIOUS DISTANCE RESISTANCE TO ELEVATOR

In addition to physical resistance, there will be a case that distance to elevator is led to conscious resistance, such as “I will not use the elevator because it is too far”.

In this study, we evaluated the conscious distance resistance to an elevator. Kishi’s Logit PSM (KLP) was applied for the analysis.

4.2 KISHI’S LOGIT PSM\(^{56}\)

In this study, Kishi's Logit PSM (KLP) was used for the contribution analysis. KLP was
improved from Price Sensitivity Measurement (PSM).

In the KLP method, consumers are shown a product and then are asked to price the product at four different levels: “reasonable,” “expensive,” “too expensive to be willing to buy,” and “too cheap to be willing to buy.” Based on the pricing data collected, a relative cumulative frequency graph was established and the intersections in the graph were used as reference price indicators. KLP uses relative cumulative frequencies that have been regressed by using the Logit model (Figure 4).  

\[
T = \frac{1}{1 + \exp F(x)}
\]

where

\(F(x) = ax + b\)

- \(T\): relative cumulative frequencies
- \(x\): price
- \(T_1, F_1\): should be less expensive
- \(T_2, F_2\): should be more expensive
- \(T_3, F_3\): too expensive to willing to buy
- \(T_4, F_4\): too cheap to willing to buy

relative cumulative frequencies

![Figure 4  KLP reference price indicators](image)

From Figure 4, the following reference price indicators can be obtained:

1) \(P_1\) (minimum price): When it is below this price, there are more people that think it is too cheap to be willing to buy. It is the minimum price for the entire consumer population

2) \(P_4\) (maximum price): When it is above this price, there are more people that think it is too expensive to be willing to buy. It is the maximum price for the entire consumer population

3) \(P_3\) (standard price): It is the same number of the people who think reasonable or expensive. So it is neither expensive nor cheap for the entire consumer population, based on which reasonable prices is set.
4) $P_2$ (reasonable price): The average price which consumers feel is reasonable for the quality.
5) $P_1$ to $P_4$ (acceptable price range): It is the price range acceptable for the entire consumer population, which distributors should aim to offer.
6) Sense of reasonability: Feeling of cost between the price levels at which the entire consumer population begins to feel reasonable and the minimum price.

**4.3 APPLICATION OF KISHI’S LOGIT PSM**

An evaluation such as “cheap” or “expensive” is subjective. KLP makes those evaluations objective from the intersection point of each relative cumulative frequency. Indicators of KLP are composed under the concept that, for example, those who think a price cheap are “more” or “less” than those who think it expensive.

On the other hand, an evaluation such as “near” or “far” is also subjective. Conscious distance resistance is also subjective, and according to the number of those that think it is “near” is large or small, we can evaluate conscious distance resistance objectively. KLP utilizes individual subjective evaluations to objectively identify degrees of the whole group's evaluations. According to this concept, we apply KLP for evaluation of conscious distance resistance by replacing a price with a distance in KLP.

The survey questions used in this study are shown on Table 3. We replaced “cheap” with “near”, “expensive” with “far” and “buy” with “use elevator”. And the question “too near to be willing to use” is removed because near location of an elevator is always desirable.

<table>
<thead>
<tr>
<th>Table 3  Questions used in KLP to measure conscious distance resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) How far is an elevator located when you feel it is near enough to use?</td>
</tr>
<tr>
<td>2) How far is an elevator located when you use it although you feel it is far?</td>
</tr>
<tr>
<td>3) How far is an elevator located when you do not use it because it is far.</td>
</tr>
</tbody>
</table>

The relative cumulative frequency of each question is revolved by the logit model (figure 5), and indicators can be found as follows.

![Figure 5](image)

**Figure 5** Application of KLP for conscious distance resistance

1) $L_1$: Maximum Distance
When the distance exceeds $L_1$, it is suggested that more people think the elevator is located too far to be willing to use it. $L_1$ is supposed to be the maximum distance for the entire passengers.

2) L2: Standard Distance
At L2, the number of people who think it is near or far is the same. When the distance is below L2, it indicates that more people think an elevator is located near enough for them to be willing to use it. So a reasonable distance should be set at this point. Maximum distance is defined as the maximum consciousness distance resistance among the above-mentioned indicators.

4.4 ANALYSIS OF CONSCIOUS DISTANCE RESISTANCE TO ELEVATOR

(1) OUTLINE OF THE EXPERIMENT

To analyze conscious distance resistance, we made an experiment focusing on elderly people on January 26th, 2001. Subjects were 11 elderly people; 7 males and 4 females. Everyone was over 60 years old, 7 people were over 70 years old.

In the experiment, subject stood in front of stairs on the assumption that they were on the platform. We asked the subjects to suppose that they were on the platform of a subway station as well as were going to move to the ticket gate on the upper floor by using the upstairs in front of them or elevator. An object likened to an elevator was moved slowly away from the subject little by little (Figure 6), and the subject answered to the following question:

Question: When the object likened to an elevator is going away, please answer the distance you feel that is near to use, far to use and too far to use, respectively.

The experiment was made supposing two situations; going down stairs (Experiment 1) or going up stairs can be chosen instead of using elevator.

(2) The result of the experiments by KLP

The result of Experiment 1 by KLP is shown in Figure 7. The intersection indicates the Maximum Distance is 20m and the Standard Distance is 13m. Experiment 2 is analyzed in the same way and the Maximum Distance is 15m and the Standard Distance is 11m (Table 4).

Both the Standard Distance and Maximum Distance of Experiment 1 are longer than those of Experiment 2. Elderly people depend on elevator when going down rather than going up. The result in Figure 2 shows that people feel a danger when they go down stairs.
Figure 7  The result of Experiment 1 by KLP

Table 4  Results of experiments by KLP

<table>
<thead>
<tr>
<th></th>
<th>Experiment 1 (Going down stairs is selective.)</th>
<th>Experiment 2 (Going up stairs is selective.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Distance</td>
<td>20m</td>
<td>15m</td>
</tr>
<tr>
<td>Standard Distance</td>
<td>13m</td>
<td>11m</td>
</tr>
</tbody>
</table>

5. PLANNING PROCESS OF ELEVATOR LOCATION

5.1 RESTRICTION LIMIT OF PASSENGERS

As for location of elevator, it cannot necessarily be located in the place which satisfies passengers because of structural and spatial restrictions of the station. Therefore, elevators could be located in a tolerable distance from the main traffic line for passengers.

Passenger’s tolerable distance can be analyzed from both the physical and the conscious distance resistance.

Figure 8  The relation of restrictions from the viewpoint of passengers

In Figure 8, the limit of physical resistance is X and that of conscious distance resistance is Y, or vice versa. In the section A, both physical and conscious distance resistances are reduced. In the section B, only either of them is reduced. In the section C, both are not reduced. The restriction limit of passengers should be X in order to reduce the both resistances.

5.2 THE LIMIT OF PHYSICAL RESISTANCE

If the route from a platform to a ticket gate is assumed like Figure 9, Equation (6) and (7) are drawn from Equation (1). By these equations, we can get $X_1$ where kinetic energy consumption of stairs and that of elevator use are the same. This point is defined as the limit...
of physical resistance.

The case of using stairs \[ E_1 = X_1 + 1.418 H \text{ \ (m)} \] (6)

The case of using elevator \[ E_2 = X_1 + X_2 + 0.291 H \text{ \ (m)} \] (7)

where

\( H \): the number of stairs

![Diagram](image)

**Figure 9** Overview of the subject station in this study

### 5.3 THE LIMIT OF CONSCIOUS DISTANCE RESISTANCE

The maximum distance of KLP is equivalent to the limit of conscious distance resistance.

### 6. LOCATION PLANNING OF ELEVATORS CONSIDERING PHYSICAL AND CONSCIOUS RESISTANCE

We calculate the values of X and Y of Figure 9 in the case of Experiment 2, as a case study where going upstairs is an option.

From the result of the experiment, the limit of conscious distance resistance is assumed to be 15m. In the experiment, when the number of existing stairs is 30, the limit of physical resistance becomes about 27m.

![Diagram](image)

**Figure 10** Relation of restrictions by Experiment 2

It was found that the limit of conscious resistance was shorter than that of physical resistance. In the section B where conscious resistance was from 15m to 27m, no reduction effect of conscious distance resistance was recognized. In the section C where conscious resistance
was over 27m, no reduction effect of both resistances were identified. It can be said that the reduction effect of both resistances appears when an elevator is installed within 15m from the stairs. When an elevator is installed at a platform with going-up 30 stairs, an elevator should be located for elderly people within 15m from the stairs.

7. CONCLUSION

In this study, we proposed the method of location planning of elevators considering physical and conscious resistances. No standard of locating elevator has been stipulated as of now in the Barrier-Free Transportation Law in Japan. The process proposed in this study enables properly locating elevator considering passengers’ acceptable distance.

In the experiment of this study, the origin to measure conscious distance resistance was set at the bottom of stairs. In the future study, we will analyze various spatial relations between stairs and elevators.

REFERENCES

2) Takeshi SIMIZU, Yoshiyuki OSHIMA and Shin-ichiro KATO; A Study on Concept of Traffic Nodal Point, Proceedings of the 49th Annual Conference of the Japan Society of Civil Engineers, 4, pp946-947, 1994
4) Toshiaki KIN, Naoki KITAMURA, Masaru KONDO and Minoru YAMADA; A Study on Walking Route Choice between Stairs and Escalator Considering Disabled People, Papers on City Planning, No.35, pp583-588, 2000