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Evaluation of the Subway-Bus Transfer System in Sapporo City by an Experimental Planning Model

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Abstract

Following the construction of the subway system in Sapporo City (which was originally built for the 1972 Winter Olympics), the public transportation situation the changed drastically. For instance, to solve the surface traffic problems of midtown area, a transfer system between the subway and buses was introduced.

In order to facilitate the passengers requirement and render the transfer system as convenient as possible, bus terminals were strategically located at major subway stations and the bus routed re-organized so that these terminals become the bus transport centers. This study offers an experimental planning model for effecting a viable subway extension plan for the future. The model was constructed after analyzing data extracted from an attitudinal survey taken prior to the completion of the subway extension. A similar survey, by interviewing the same people, was taken again after the subway extension was completed. In the case of the Momijidai area, which is the study area of this paper, the estimated value of the experimental planning model (the estimated bus-subway utilization rate of 53.3 percent) coincides with actual values (51.2 percent).

1. Introduction

The city of Sapporo (Which has a population of 1,504,000) is now the fifth largest city in Japan. After the construction of the subway system (which was originally built for the 1972 Winter Olympics), the public transportation situation changed drastically. Prior to this, the main methods of public transport were the bus and streetcar. To solve the surface traffic problems of the midtown area, a transfer system between the subways and buses was introduced. In order to facilitate the passengers requirement and render the transfer system as convenient as possible, bus terminals were strategically located at major subway stations and the bus routes re-organized so that these terminals became the bus transport centers. One of the better features of the Sapporo subway-bus transfer system is the "transfer discount fare scheme". This service was initiated to save the passenger both time and money.

In the city of Sapporo, the total length of the two subway lines is 31 kilometers and, in the future, the distance will be extended much further. However, to do this, it is necessary to adopt a more accurate formula for assessing future passenger utilization of

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the subway and bus systems.

The conventional method of estimating passenger utilization is the "Person Trip Survey". This survey is taken throughout the entire urban area and asks passengers to offer opinions on their choice of transportation based only on the travel time required and fare of the transport. When data from this survey is analyzed, it does not present an accurate model which can be used in the planning of future subway extensions since the extensions will affect only a limited area of Sapporo.

This study offers an experimental planning model for effecting a viable subway extension plan for the future. The model was constructed after analyzing data extracted from attitudinal survey (a survey conducted to gauge the subjective evaluation of transport modes by the travellers)¹⁾ taken prior to the completion of the subway extension. A similar survey, which interviewing the same people, was taken again after the subway extension was completed. The effectiveness of the experimental planning model was examined by comparing the anticipated value of the model (constructed from the attitudinal data collected prior to the extension) to the actual values realized (ascertained from the post completion survey) after completion of the subway extension²⁾.

2. Study Area

The Momijidai area, which is the study area of this paper, is located 12-15 kilometers from the center of Sapporo. It is rapidly being developed as the "second center" of the city. The transportation situation on the Momijidai area changed drastically after the completion of the subway extension in March 1982. Prior to the subway extension, there were three ways to travel by public transport from the Momijidai area to the center of the city: the first was a 30 minutes bus ride to the Shiroishi Subway Station (located 4 Kilometers from the city center) with a subsequent transfer to the subway; the second was a 10 minutes bus ride to the train station and a train ride to Sapporo; the third was a bus which served directly to the center of the city. In March 1982, the subway line was extended from Shiroishi Station to the Momijidai area and the bus-subway transfer system was implemented. Because of this, the travel time to the center of city decreased dramatically. Figure1 summarizes the service level these three transport systems during

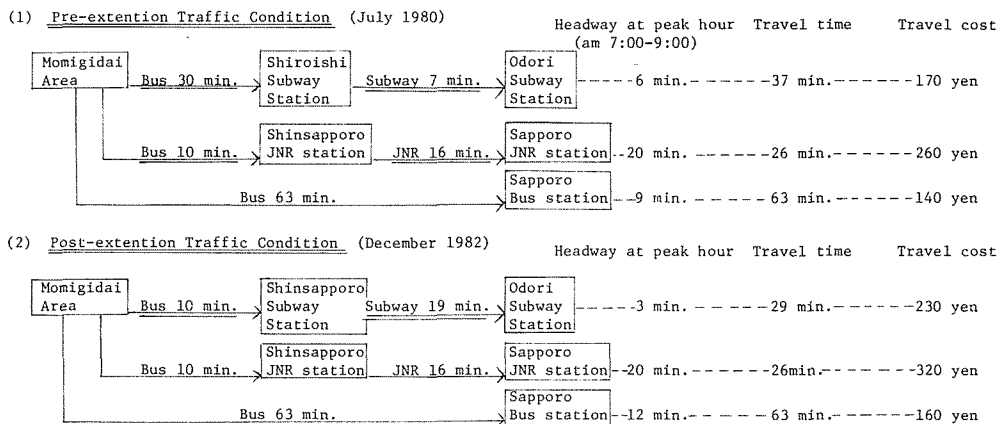


Fig.1 Changes in the level of Service of public Transport

the peak hours by looking at three factors: the operation intervals (headway); the travel time; and the travel cost. As can be seen from the Figure, the improvement of the bus-subway transfer system reduced the travel time by 8 minutes and doubled the amount of available transport service.

3. The Experimental Planning Model

(The Model of the Design of Experiment)³⁾

The design phase of the experimental planning model is divided into two parts: the configuration of the public opinion survey (according to the experimental plan); and the construction of the model based on the data collected. The survey (which uses numerical values) takes two primary factors into consideration: the fare and the required travel time for the transport system to be employed. The passenger is asked to make his choice of transport in the following manner; "If you have a public transportation system which carries you to your destination in 40 minutes and costs you 120 yen, which do you prefer: your personal vehicle or the public transportation system". Three mathematical elements can be extracted from this query. The first element is the mathematical factors which are generated by the survey. The second element is the number of factors and the levels of each factor. The third element is the orthogonality between the factors.

By using the experimental planning model when analyzing the three elements, it becomes possible to make rational judgements about the survey. The following is an explanation of each element:

1) The factors: The first step is analyzing the factors of the survey and differentiating between restricted conditions and input conditions; the restricted conditions being those which the analysts can not do anything about, and the input conditions being the ones which can be manipulated.

The only factors which are used for the experimental planning model are the input conditions because propriety of the input data is not considered statistically and mathematically, the analysts hence have to make decisions based on their experience and intuition. In addition, if the input factors are inadequate, the data will be impossible to analyze since the answers will be unreliable. To ensure their propriety, the input conditions are examined by the size of their error ratio which becomes apparent as a result of an analysis of variance which is carried out according to the limits prescribed by the experimental planning method.

2) Number of Factors and Levels of Each Factor: The second feature of the experimental planning model was the attempt at reducing the number of times the surveys had to be used by employing the orthogonal array. As an example, let's consider a situation having six factors which influence the choice of transportation and each of these factors has two levels. In this case, the possible combination of the numbers can be given by,

$$2^6 = 64$$

If a survey is conducted using 64 combinations that can affect decisions, what possible kinds of information can be obtained? Table 1 gives a summary of the effect of factors and their degree of freedom. The number of principal and interaction effects can be obtained through six combination of numbers. However, even if it possible to obtain information

concerning the interactive effects of three or four factors, it is difficult to understand the information from a technical point of view. Therefore, the supposition is made that “interactive effects of more than three factors are disregarded”. For example, if only the main effect is required, the survey may be conducted 8 times using the L-8 orthogonal array. The aforementioned method is called “the method of partial operation” and it is possible to operate this method quite effectively by using orthogonal arrays.

3) Ensuring Orthogonality Between the Explaining Variables: Table 2 shows L-8 orthogonal array with the number of factors to be selected listed by column and the combinations of the factors and their levels listed by rows. “1” is the first level of each factor and “2” is the second level. This table displays the following characteristics:

a) The same number appears equally in each column. That is, “1” and “2” appear four times in each column of the L-8 orthogonal array.

b) If combinations of certain numbers are made by picking any two rows, the same combinations appear in the same frequency. In the array, each combination of 1-1, 1-2, 2-1 and 2-2 appears twice. Following this pattern, if the product and the sum are made by applying (+1) in the case of “1” and (-1) in the case of “2”, the result is,

$$(1 \times 1) + (1 \times (-1)) + ((-1) \times 1) + ((-1) \times (-1)) = 0.$$

From this result, it can be seen that this is an orthogonal arrangement.

Table-1 Effect of the Factor and Degree of Freedom

| Effect of the Factor | Degree of Freedom |
|-----------------------------------|-------------------|
| principal effect | ${}^6C_1 = 6$ |
| interactive effect of 2 factors | ${}^6C_2 = 15$ |
| interactive effect of 3 factors | ${}^6C_3 = 20$ |
| interactive effect of 4 factors | ${}^6C_4 = 15$ |
| interactive effect of 5 factors | ${}^6C_5 = 6$ |
| interactive effect of 6 factors | ${}^6C_6 = 1$ |
| Total number of Degree of Freedom | 63 |

Table-2 Othogonal Arrey L-8 (2⁷)

| Factors No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|-------------|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 1 | 2 | 2 | 2 | 2 |
| 3 | 1 | 2 | 2 | 1 | 1 | 2 | 2 |
| 4 | 1 | 2 | 2 | 2 | 2 | 1 | 1 |
| 5 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| 6 | 2 | 1 | 2 | 2 | 1 | 2 | 1 |
| 7 | 2 | 2 | 1 | 1 | 2 | 2 | 1 |
| 8 | 2 | 2 | 1 | 2 | 1 | 1 | 2 |

When natural phenomena are used as the objects of science, it is tacitly understood that the primary characters observed by Galileo (physical characters such as mass, length and speed) and the secondary ones (charaters which exist in senses such as color, smell and taste) are orthogonal. That is, analysis is usually carried out under the assumption that the secondary characters rarely influence the laws and relationships pertaining to the primary characters. However in the case of social phenomena, the primary and secondary characters are not always orthogonal. For example, if the consumption utility function (used in economics) is examined, can it be asserted that the relationship between consumption and income cannot be influenced by “the whim of the individual”? At the present time, it is taken for granted that in choosing a model of transportation utilization, comfort and safety should also be considered in addition to the required travel time and the cost of traveling. In social phenomena, the secondary characters influence the primary

ones considerably. Because of this, mathematical and statistical models which are constructed by putting importance only on the primary characters suffer from a degradation in the reliability of their probability results.

As explained in 1), 2) and 3) of Part 2, it becomes possible to plan a more rational attitudinal survey by using the experimental planning model. The experimental planning model which is discussed in this study, is of the kind that is designed by using the attitudinal survey data collected and making the most of the positive characteristics of the orthogonal array. The characteristics of this model are: the special features of the data are reflected directly; the orthogonality between the factors is ensured; and the quantity of information is dispersed evenly throughout the area from which the data was collected. In this study, the aggregate logit model was used to design the experimental planning model.

4. Planning and Outline of the Attitudinal Survey by Means of the Experimental Planning Model^(4),5)

The aim of this study is to estimate the change of public transport available due to the extension of the subway by means of the experimental planning model. To accomplish this. It is necessary to set up factors and levels which would likely influence a change in the availability of public transport brought about by the subway extension. Five factors and a small number of levels for each factor were set up in Table 3.

Table-3 Factor and Level

| Factor | Level | | |
|---|-----------|---------------|---------|
| | Level 1 | Level 2 | Level 3 |
| Purpose of Transport | Commuting | Non-Commuting | ——— |
| Bus Travel Time to the Subway | 5 min. | 10 min. | 15 min. |
| Discount Fare for the Transfer | 150 yen | 170 yen | 190 yen |
| Headway of the Direct Bus | 15 min. | 30 min. | 45 min. |
| Headway of the Feeder Bus to the Subway | 5 min. | 10 min. | 15 min. |

These factors and levels are explained as follows:

a. Purpose of Transport: Two levels were established, commuting and non-commuting (shopping, medical trips, etc). For this factors, two kinds of questionnaires (one for the commuters, the other for non-commuters) were devised to assess the change in public transportation available depending upon the purpose of travel.

b. Time Required for the Bus Ride to the Subway Station: This factor experienced the greatest change after the completion of the subway extension. The improvement is notable. Prior to the subway extension when the survey was first conducted, the bus ride took 30 minutes. For this factor, three time requirement levels were established for the bus ride to the subway station after the completion of the extension; 5 minutes, 10 minutes and 15 minutes.

c. Discount Fare for the Transfer: This factor did not change that much after the

completion of the extension ; but, according to the passengers, they considered it to be most important factor. Three levels were set up ; 150 yen, 170 yen and 190 yen.

d. Operating Interval (time) of the Bus which goes directly to the city center (Direct Bus): The direct bus is a transportation system which competes directly with the subway. The interval of operation is the only factor which is assumed to be important. For this reason, this factor was established. The average interval was 9 minutes during the peak hours when survey was first conducted. However, it is expected that, after the completion of the extension, the service would deteriorate and three operational intervals were set up ; 15 minutes, 30 minutes and 45 minutes.

e. Operating Interval of the Feeder Bus Service to the Subway Station: As the interval of operation (according to the survey results) during the peak hours was 6 minutes, it was considered to be a frequent service. With an anticipated degradation in operating intervals, three levels were established ; 5 minutes, 10 minutes and 15 minutes.

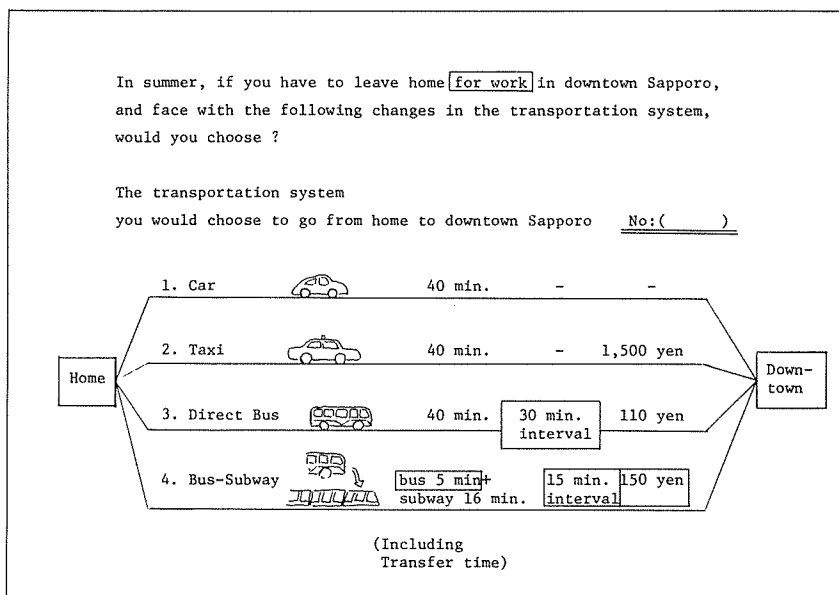
If the above factors are combined with all of their levels, it gives

$$2 \times 3 \times 3 \times 3 \times 3 = 162.$$

This means that there is a possibility that 162 kinds of questionnaires would be required if all the combinations are considered. To avoid this, the reduction in the number of surveys was calculated by using the orthogonal array mentioned previously. The L-18 orthogonal array was employed and this reduced the types of questionnaires required from 162 to 18. Table 4 shows how each factor is combined with the levels in the 18 questionnaires. One example of the questionnaire is shown in Figure 2. As can be observed by this figure, average values (compiled from totals of the individual surveys) are given for each level of the factors which were selected by the experimental planning model so that the analysts could easily make comparisons and judgements.

Table-4 Orthogonal Array (L-18)

| Factor Survey Sheets NO. | Purpose of Transport | Bus Travel Time to the Subway | Discount Fare for the Transfer | Headway of the Direct Bus | Headway of the Feeder Bus to the Subway Station |
|-----------------------------------|-------------------------|-------------------------------------|---|---------------------------------|---|
| 1 | commuting | 5 | 150 | 15 | 5 |
| 2 | commuting | 5 | 170 | 30 | 10 |
| 3 | commuting | 5 | 190 | 45 | 15 |
| 4 | commuting | 10 | 150 | 15 | 10 |
| 5 | commuting | 10 | 170 | 30 | 15 |
| 6 | commuting | 10 | 190 | 45 | 5 |
| 7 | commuting | 15 | 150 | 30 | 5 |
| 8 | commuting | 15 | 170 | 45 | 10 |
| 9 | commuting | 15 | 190 | 15 | 15 |
| 10 | non-commuting | 5 | 150 | 45 | 15 |
| 11 | non-commuting | 5 | 170 | 15 | 5 |
| 12 | non-commuting | 5 | 190 | 30 | 10 |
| 13 | non-commuting | 10 | 150 | 30 | 15 |
| 14 | non-commuting | 10 | 170 | 45 | 5 |
| 15 | non-commuting | 10 | 190 | 15 | 10 |
| 16 | non-commuting | 15 | 150 | 45 | 10 |
| 17 | non-commuting | 15 | 170 | 15 | 15 |
| 18 | non-commuting | 15 | 190 | 30 | 5 |



Note ; : There exists some discrepancies in these values in the survey sheets

Fig.2 Questionnaire

The survey was conducted twice; once prior to the subway extension and once afterward. The first survey conducted: from 15-24 July, 1980 and the second from 26-28 December, 1982 (nine months after the subway extension was completed on March 21, 1982). The second survey used the same sampling list of households as the first. The first survey was conducted by asking the commuters and non-commuters of each household to participate in the attitudinal survey. Additionally, they replied to queries on the actual conditions of the transportation situation. In the second survey, only research on the transportation situation was conducted involving only the commuters of each household. 540 households were chosen for sampling. The selection for sampling was made according to the distance from the subway station or bus stop of each household. The results of the distribution and collection the two surveys are shown in Table 5. The number of people sampled which were varified as being the same in both surveys amounted to 316.

Table-5 Survey Sheets Distribution and Return Rate

| | | |
|----------------------|---|---------------|
| FIRST SURVEY (1980) | Distributed Household | 540 household |
| | Returned Household | 514 household |
| | Returned Rate(Household) | 95.4 % |
| | Number of Distributed Survey Sheets | 626 sheets |
| | Commuting | 508 sheets |
| SECOND SURVEY (1982) | Distributed Household | 462 household |
| | Returned Household | 439 household |
| | Returned Rate(Household) | 95.0 % |
| | Number of distributed Survey Sheets(Commuting only) | 566 sheets |

5. Construction of the Experimental Planning Model⁶⁾

The construction of the experimental planning model is shown as follows (using the attitudinal survey which was devised by the L-18 orthogonal array): Table 6 shows the number of people who preferred the bus-subway transfer system and the ratio of each of the 18 types of questionnaires. Dispersion analysis was conducted using the attitudinal data. By means of this analysis, it is possible to know the propriety of the factors and their

Table-6 The Rate of Bus-Subway Transfer System Usage from the Attitudinal Survey

| Questionnaire Number | Transfer System Users (person) | Sample Number (sheets) | Usage Rate (%) |
|----------------------|--------------------------------|--------------------------|----------------|
| 1 | 44 | 65 | 67.7 |
| 2 | 46 | 72 | 63.9 |
| 3 | 43 | 72 | 59.7 |
| 4 | 51 | 75 | 68.4 |
| 5 | 48 | 78 | 61.5 |
| 6 | 54 | 81 | 66.7 |
| 7 | 58 | 78 | 74.4 |
| 8 | 47 | 82 | 57.3 |
| 9 | 38 | 75 | 50.7 |
| 10 | 41 | 52 | 78.8 |
| 11 | 43 | 55 | 78.2 |
| 12 | 44 | 61 | 72.1 |
| 13 | 45 | 58 | 77.6 |
| 14 | 50 | 70 | 71.4 |
| 15 | 43 | 59 | 72.9 |
| 16 | 49 | 69 | 71.0 |
| 17 | 41 | 71 | 57.7 |
| 18 | 45 | 68 | 66.2 |

Table-7 Dispersion Variance

| Factor | Deviation Square | Degree of Freedom | Variance | F-Value | Coefficient of Determination |
|---|------------------|-------------------|----------|---------|------------------------------|
| Purpose of Transport | 317.56 | 1 | 317.56 | 25.69 | 28.3 |
| Bus Travel Time to the Subway | 197.75 | 2 | 98.88 | 8.00 | 15.6 |
| Discount Fare for the Transfer | 264.37 | 2 | 132.19 | 10.69 | 21.8 |
| Headway of the Direct Bus | 33.75 | 2 | 16.88 | 1.37 | 0.2 |
| Headway of the Feeder Bus to the Subway | 124.25 | 2 | 62.13 | 5.03 | 8.7 |
| Interactive Effect (Purpose - Bus Time) | 53.38 | 2 | 26.69 | 2.16 | |
| Error | 74.14 | 6 | 12.36 | | 25.4 |
| TOTAL | 1065.19 | 17 | | | 100.0 |

respective levels which were established when devising the attitudinal survey. From this, it is also possible to determine which factor will influence the rate of utilization of the bus-subway transfer system. Table 7 shows the results of dispersion analysis. The coefficient of determination (δ) in this analysis shows the variation of each factor in total variation and is given as follows ;

$$\delta_A = \frac{\text{Variation of Factor A}}{\text{Total Variation}} = \frac{S_A - \phi_A \times V_E}{S}, \quad (1)$$

where δ_A =coefficient of determination of factor A, S_A =variation of factor A, S =total variation, ϕ =degree of freedom of factor A and V_E =dispersion of error. From the dispersion analysis (refer to Table 7), the following can be ascertained :

1) The coefficient of determination's error factor is 25.4 per cent. The accuracy of the variation in the rate of utilization is 74.6 per cent and this will be sustained by those factors. This makes it clear that the factors and their levels which were devised by this study are appropriate.

2) The factor having the greatest influence of the utilization rate is the purpose of transportation. The other factors (in descending order of precedence) are: discount transfer system ; time required for the bus ride to the subway station ; bus operating intervals.

The model for choosing the transportation system was constructed by employing the aggregate logit model, making the utilization rate of the bus-subway transfer system the dependent variable of the study. The equation is given by

$$P = \frac{1}{1 + e^{G(X)}} \quad (2)$$

$$G(X) = -3.12 + 0.39 \times X_1 + 3.29 \times 10^{-2} \times X_2 + 9.60 \times 10^{-3} X_3$$

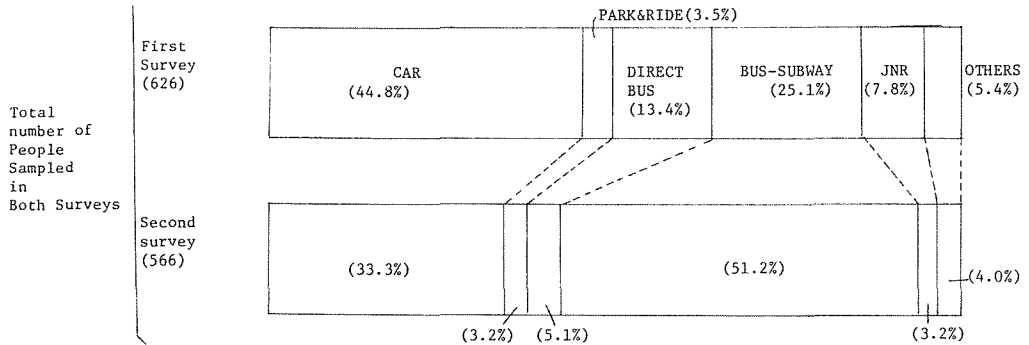
$$-2.15 \times 10^{-3} \times X_4 + 2.68 \times 10^{-2} \times X_5,$$

where P =rate of choice of the bus-subway transfer system, X_1 =the purpose of transportation (using dummy values of 1 for commuting and 0 for non-commuting), X_2 =time required for the bus ride to the subway, X_3 =discount fare for the transfer, X_4 =intervals of operation of the direct bus and X_5 =intervals of operation of the feeder bus service to the subway station. The determinant coefficient of this model is 0.76.

6. Examination of the Effectiveness of the Experimental Planning Model

To understand the influence of the subway extension on the actual utilization requires a comparison between the transportation situation for the period prior to the extension (July 1980) and the situation after the extension was completed (December 1982). The comparison presented a clear picture of the changes that occurred (Figure 3).

Fig.3 Transport Mode Distribution (I)



Following is a summary of the influence of the extension on the actual utilization of transportation with reference to Figure 3.

1) Due to the subway extension, the number of passengers who use the bus-subway transfer system doubled from 25.1 per cent to 51.2 and the total ratio of other passengers who moved from other means of transport was 26.1 per cent.

2) The ratios of passengers who changed from each transportation system to the bus-subway system are given as follows: direct bus passengers, 62.0 per cent; the bus-train passengers, 59.0 per cent; automobile passengers, 26.0 per cent; "park and ride" passengers, 8.6 per cent.

In the following, the effectiveness of the experimental planning model is examined based on the actual utilization of the transportations systems after the extension of the subway was completed. The actual value of each level of each factor was inserted into the experimental planning model (which was constructed in the previous section) to compare

Table-8 The Estimated Value by the Model and the Real Value

| | |
|--|--------------|
| Input Values in the Model | |
| Purpose of Transport | — commuting. |
| Bus Travel Time to the Subway | — 10 min. |
| Discount Fare for the Transfer | — 230 yen. |
| Headway of the Direct Bus | — 12 min. |
| Headway of the Feeder Bus to the Subway Station | — 3 min. |
| Estimated Value of the Experimental Planning Model | 53.3 % |
| Real Value | 51.2 % |

the estimated value with the real value. Table 8 shows the level value of the factors which were inputted into the model, the estimated value and the real value. From this table, it becomes clear that the real value (51.2 per cent) is approximately equal to the estimated

value (53.3 per cent) of the experimental planning model. As a result, it proved that the experimental planning model (constructed from the attitudinal survey) can favorably estimate the travel behavior of the people in the future.

7. Conclusions

The aim of this study is to analyze the change in transportation available after the completion of the subway extension by using the experimental planning model for the Momijidai area in Sapporo. By means of this analysis, the examination of the effectiveness of the model was carried out.

The summary of the effectiveness of the subway extension (which was the object of the actual analysis) is as follows:

1) The change of transportation available after completion of the subway extension: The total change from some other means of transport to the subway system amounted to 60 per cent. Of that total, 40 per cent had changed from personal vehicles to the bus-subway transfer system. The principle reason for the large ratio of those who changed from cars to the subway was that 45 per cent of the people in this area had always used a personal vehicle previously. The fact that the change ratio from car (which is a private transportation system) to the bus-subway transfer system was so great enables us to draw the conclusion that the subway extension was effective enough to solve the surface traffic problem in the downtown area of Sapporo.

The features of the experimental planning model which have been proposed in this study are summarized into three major points.

1) It is possible to plan an attitudinal survey with less frequency by the use of the orthogonal array.

2) It is possible to construct the model from the collected data after ensuring orthogonality between the explaining variables.

3) It is possible to check the propriety of the factors and levels which were adopted by a dispersion analysis. Additionally, it is possible to control the size of the error rate of the answers quantitatively.

As this analysis verifies the estimated value of the experimental planning model (the estimated bus-subway utilization rate of 53.3 per cent) coincides with the real value (51.2 per cent). This confirms the fact that the experimental planning model (constructed from the attitudinal survey) is extremely practical.

Finally, the problems which are foreseeable in the future are summarized as follows:

1) Planners and analysts must ensure that the pattern of distribution of the response error and the repetitive error are compatible.

2) Planners and analysts must ensure that the composition of the sampling group is distributed evenly.

3) Planners and analysts must ensure that only the essential numbers of the various kinds of attitudinal surveys are employed.

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