THE EFFECT OF THE SEIKAN TUNNEL ON INTERCITY PASSENGER TRANSPORT IN JAPAN

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1. Outline of the Seikan Tunnel Project

The Tsugaru Straits lies between Honshu, the main island, and Hokkaido in the north. (Fig. 1) Under this stretch of water, excavation is proceeding on the world's longest undersea tunnel - Seikan Tunnel.

The volume of transportation between Honshu and Hokkaido has been greatly increasing, consequently, in near future the transportation demand will surpass the ferry service capacity .

Without any improvement or a new route of transportation, the development of Hokkaido, and the economic activities of the nation would be restricted.

There were two possible systems for running a railway via the straits: build a bridge over the sea, or excavate an undersea tunnel.

In the Tsugaru Straits, the water is deep and the sea-current is rapid; thus, it is impossible in build a bridge. Therefore it was proposed in build an undersea tunnel which would offer safe transportation even in stormy weather.

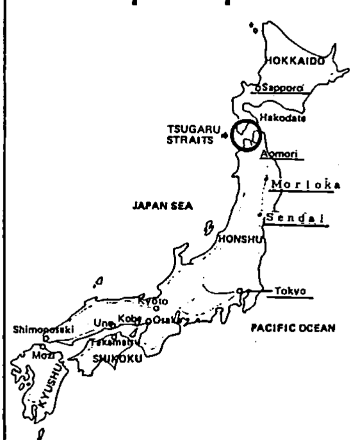
Beginning in 1946, a careful geological survey was made of the Tsugaru Straits. In 1964, excavation of the exploratory tunnels were started in observe the characteristics of faults and rock formation, and to study construction methods of excavation and sealing water inflow. By March 1971, the investigation stages were over, and in April 1971, the construction project was authorized by the government.

The geological features in the straits may be divided into three broad classes: one third consisting of andesite (Honshu side), with the other two thirds of tuff. The middle of the straits consists of tuff, Kuromatsunai-layers. On Hokkaido side, it consists of tuff, Kunnui-layers. There are nine prominent faults on the route.

Prior to the excavation of the main tunnel, the horizontal pilot tunnels and service tunnels are dug. Exploratory borings were taken to confirm the geological conditions and any presence of gushing water. Grouting for sealing water inflow were carried out when necessary. The main tunnel profile are shown in Figs. 2 and 3, respectively. In geologically unstable sections, e.g., disintegrated, or fractured zones, special methods are applied. In geologically stable zones, the tunnels are bored using the same methods as in mountain tunnelling.

The pilot tunnel was constructed under the sea bottom under direct control of the Japan Railway Construction Public Corporation. The service and main tunnels were excabated by construction companies.

Fig.1 **Map of Japan**



On March 10, 1985, the main Seikan tunnel boring was completed, connecting Hokkaido and Honshu for the first time by land. It was 21 years since the commencement of boring of the survey tunnel and 39 years since the beginning of the preliminary survey. The completion of the tunnel was expected to proved a transport route unaffected by weather and to facilitate the construction of the high-speed transit railway (Shinkansen bullet train). But what has resulted is a heated ongoing discussion as to whether the construction of the Seikan Tunnel has been worth the effort and expense. Some say the project was a failure while others say it was a great success. Such a wide division in opinion has resulted from the so-called oil shock or oil crisis of 1974 which brought about great changes in the Japanese industrial structure and transport systems - largely reducing the volume of traffic along the Seikan route. In other words, the point at issue is whether the recent decline in the expected role of Seikan Tunnel will continue far into the future.

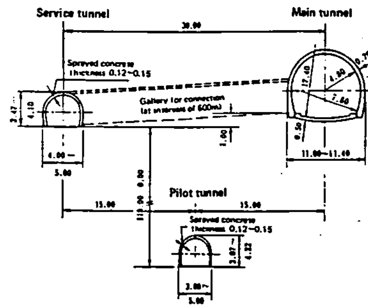
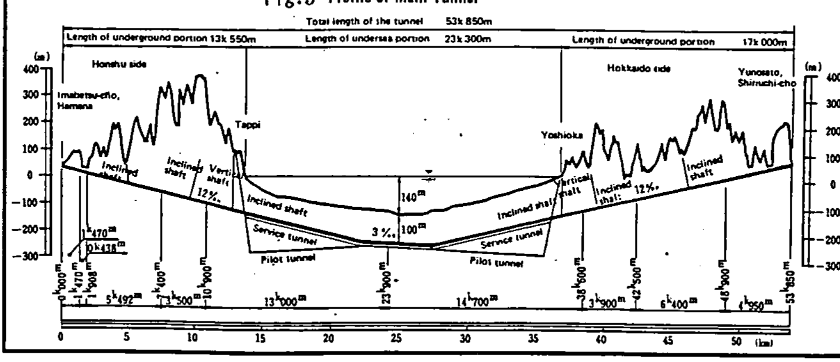


Fig.2 Standard Cross Section
(Unit: m)

Fig.3 Profile of Main Tunnel



2. Transport Between Hokkaido and Honshu

(1) Change in the volume of passenger transit

The means of passenger transit between Hokkaido and Honshu are railroad, railroad ferry, airway and car ferry. The Seikan route is very important for most of these, but is not the only route. Figure 4 shows the number of passengers between Hokkaido and Honshu classified by transport means from 1970 to 1980. It indicates that the total number stopped increasing in 1974, remaining approximately the same thereafter. The year 1974 is also notable in that the number of airway passengers surpassed that of railroad passengers. Jumbo jets were first introduced to the route between Tokyo (Haneda

Airport) and Sapporo (Chitose Airport) in 1973. Since then the number of passengers has kept growing, making the volume on this route one of the largest in the world.

Figure 5 indicates the change in the utilization rate of the Seikan route for passenger transport between Hokkaido and Honshu; peak of 65% in 1970, but decreasing thereafter. In 1974, for example, the number of people traveling along the Seikan route was 5,756,000, while that of those using other routes was 5,815,000. But by 1978 the number of travelers along the Seikan route had dropped to 3,500,000.

The following are the main reasons for the drop in utilization rate of the Seikan route:

1) The railroad fare was increased sharply around 1975-1977, making the difference with the air fare much smaller.

2) It takes 16 hours to travel from Tokyo to Sapporo by train and boat, while it takes only 4 hours by plane, including the access time between airport and city.

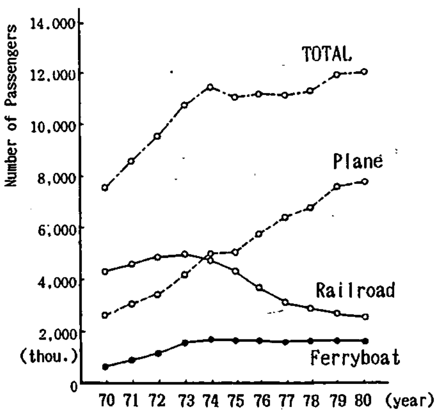


Fig.4 Number of Passengers between Hokkaidou and Honshu clssified by transport means

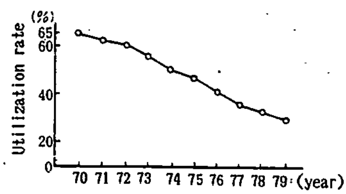


Fig.5 Change in the utilization rate of the Seikan route

(2) Change in Freight Volume

Figure 6 shows the change in the volume of freight between Hokkaido and Honshu from 1970 to 1979, classified by transport means. The volume increased with the economic development of Hokkaido but dropped at the oil shock, showing only a little increase thereafter as the economic development slowed down. Coastal shipping accounted for 80%, because most freight consists of petroleum products, coal, cement, etc. The railroad transported 20% in 1970, but only 9.6% in 1979. The car ferry's share on the other hand, increased from 1.2% in 1970 to 7.5% in 1979. Figure 7 shows the amount of cargo carried into and out of Hokkaido by the Seikan ferry (railroad ferry). The peak, 8,540,000 t, occurred in 1971, but had decreased to 4,970,000 t and 3,500,000 t by 1975 and 1980, respectively. The railroad's share decrease so rapidly because the fare was sharply raised around 1970-1972, and also because the construction of highways promoted transport by large trailer trucks.

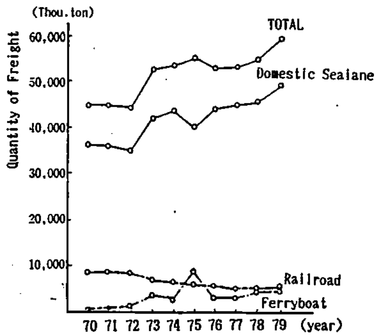


Fig.6 Change in the volume of freight between Hokkaidou and Honshu

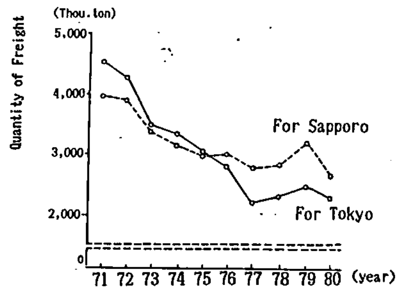


Fig.7 Amount of cargo carried into and out of Hokkaido by the Seikan ferry(railroad ferry)

3. Estimation of Utilization Rate of the Seikan Tunnel Based on the Experimental Planning Model

In Japan, long distance transport of passengers is primarily by plane, and cargo transport by truck. Thus, will it be possible for the Seikan tunnel to be fully utilized, assuming the railroad as the main user? In our research, a questionnaire was carried out to plane passengers at Chitose Airport, and their attitude was analyzed through the experimental planning model.

(1) Experimental Planning Model
(The Model of the Design of Experiment)

The design phase of the experimental planning model was divided into two parts: configuration of the public opinion survey (according to the experimental plan); and construction of the model based on the data collected. The survey, takes several primary factors into consideration: the fare, required travel time, and accessibility of the transport system to be employed. Three elements can be extracted from this model: the first, second, and third elements are the input conditions, survey effort, and orthogonality between factors, respectively. 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) Input Condition - the first step is to differentiate restricted conditions from input conditions: restricted conditions cannot be altered but input conditions can be manipulated.

The only factors used for the experimental planning model were the input conditions because the propriety of the input data has not been established statistically and mathematically: the analysts have had to make decisions based on experience and intuition. In addition, if the input factors prove inadequate, the data will be impossible to analyze since the results will be unreliable. To ensure their propriety, the input conditions are examined by the error ratio resulting from an analysis of variance carried out within the limits prescribed by the experimental planning method.

2) Survey Effort - The second feature of the experimental planning model was the attempt at reducing the survey effort by employing an orthogonal array. As an example, with a situation having six factors, each with two levels, influencing the choice of transportation, the possible combinations of items can be given by,

$$2^6 = 64.$$

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

If a survey is conducted using all 64 combinations that can affect decisions, what possible kinds of information can be obtained? Table 1 summarizes the effect of factors and their degree of freedom. The number of principal and interaction effects can be obtained through combinations of the six numbers. However, even if it were possible to obtain information concerning the interactive effects of three or four factors, it would be difficult to interpret the information from a technical point of view. Therefore, interactive effects of more than three factors were disregarded. For example, if only the main effects is required, the survey may be conducted 8 times using an L-8 orthogonal array. It is possible to operate the aforementioned 'method of partial operation' quite effectively using orthogonal arrays.

3) Orthogonality Between Factors - Table 2 shows an L-8 orthogonal array with factors listed by column and combinations of factors and their levels listed by rows. '1' is the first level of each factor and '2' is the second level. This table has the following characteristics.

Table-2 Orthogonal Arrey L-8 (2^7)

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

a) The numbers '1' and '2' appear equally in each column: i.e., '1' and '2' each appear four times in all columns of the L-8 orthogonal array.

b) If combinations of certain numbers are made by picking any two columns, the same combinations appear with the same frequency. Thus, each combination of 1-1, 1-2, 2-1 and 2-2 appears twice. Following this patter, 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.

When natural phenomena are observed scientifically, it is tacitly understood that the primary characteristics observed by Galileo (physical quantities such as mass, length, and velocity) to the secondary ones (quantities existing in the senses such as color, smell, and taste) are orthogonal. That is analysis is usually carried out under the assumption that the secondary characteristics rarely influence the laws and relationships pertaining to the primary characteristics. However with social phenomena, the primary and secondary characteristics 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 cost. In social phenomena, the secondary characteristics greatly influence the primary ones. Because of this, mathematical and statistical models constructed using only primary characteristics produce unreliable 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, was designed using the collected attitudinal survey data and taking advantage of the positive characteristics of the orthogonal array. The model is characterized by the following: special features of the data are reflected directly, orthogonality between factors is ensured, and information quantity is distributed evenly over the area from which the data was collected. In this study, the aggregate logit model was used to design the experimental planning model.

(2) Analysis of Passengers' Attitude Toward the Seikan Tunnel

The objective of this paper is to estimate change in the number of passengers who will use the Seikan Tunnel upon completion - i.e., railroad, instead of plane.

The main factors affecting the choice of transport means are the fare, travel time, waiting time, luggage, weather and season. People make decisions taking these factors into consideration, sometimes ignoring one or two. The decision making process can be mathematically described by the transport mode choice model (modal choice model). To construct the modal choice model, the factors which are in conformity with the research purpose must first be determined and chosen. Past experience has indicated the importance of the following four factors: destination, weather, presence (or absence) of the Shinkansen, and travel purpose.

Table 3 shows the factors with standards adopted for our research. Their determination is based on the following considerations:

Table-3 Factor and Level

Mark	Factor	Level-1	Level-2	Level-3	Level-4
A	Destination	Aomori	Morioka	Sendai	Tokyo
B	Weather	Fine	Stormy	–	–
C	Existence of Shinkansen	Existent	Absent	–	–
D	Purpose of transportation	Business	Sight-seeing	–	–

(i) Factor A (Destination)
In considering the utilization of the Seikan Tunnel, it is very important to know the distance to the traveler's destination, especially since planes are increasingly being used for intermediate-distance transport.

(ii) Factor B (Weather)
A great problem with the Seikan railroad ferry is its dependency on weather conditions, as demonstrated by the Toya-Maru disaster which was the worst shipwreck in Japan. Therefore this factor was adopted and its effect rate examined.

(iii) Factor C (Presence of Shinkansen)
It has been reported that since the initiation of the Tohoku Shinkansen, greatly reducing the time required for travel between Tokyo and the Tohoku District, the number of people using the railroad has considerably increased. The presence of the Shinkansen would be very important in Seikan Tunnel utilization.

(iv) Factor D (travel purpose)
It is well known that travel purpose has much to do with the choice of transport means. In our research, business and sightseeing were adopted as travel purposes to observe their effect on Seikan Tunnel utilization.

If all factors and standards in Table 3 were combined, there would be 32 cases ($4 \times 2 \times 2 \times 2$), whose thorough investigation would require a large effort. Therefore, an L-8 orthogonal array table was formulated as shown in Table 4, and 8 kinds of questionnaires were produced. This reduced effort does not mean a reduction in reliability of the result. A copy of the questionnaire (No. 8) made from Table 4 is shown in Fig. 8.

Table-4 Orthogonal Array (L-8)

	A		BCeD	A	B	C	D
	123		4567	Destination	Weather	Shinkansen	Purpose of Tr.
1	111	= 1	1111	Aomori	Fine	Presence	Business
2	111		2222	Aomori	Stormy	Absence	Sightseeing
3	122	= 2	1122	Morioka	Fine	Presence	Business
4	122		2211	Morioka	Stormy	Absence	Sightseeing
5	212	= 3	1212	Sendai	Fine	Presence	Business
6	212		2121	Sendai	Stormy	Absence	Sightseeing
7	221	= 4	1221	Tokyo	Fine	Presence	Business
8	221		2112	Tokyo	Stormy	Absence	Sightseeing

II. In this questionnaire, we would like to ask if you would travel via the Seikan Tunnel under the conditions given below. The state of transport available is not necessarily similar to that of the present day.

Question 1 - Suppose you are going from Sapporo to Tokyo on sightseeing. The weather is stormy. The fare and required time are given in the figure below.
What are the transport means of your first and second choice?

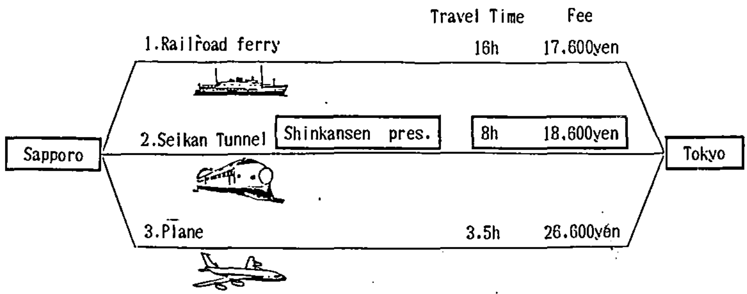


Fig.8 8th Case of Questionnaire

The survey was conducted in January, 1984, in the departure lounges of Chitose Airport. Nine researchers gave out the questionnaires at random, collecting them just before the people got on board - 1,672 valid forms were obtained.

The answer tally is shown in table 5. For example, of the 205 people answering questionnaire No. 8, 7 (3.4%) preferred the Seikan ferry, 119 (58.0%) the Seikan Tunnel, and 79 (38.5%) planes.

The different utilization rates for each transport means found on the 8 forms, were analyzed by variance analysis.

The results of the variance analysis based on the utilization rate of Seikan Tunnel (shown in Table 6), used the dispersion of error, and degree of freedom and variation of each factor. The coefficient of determination shows the effect of each factor on the total variation. The coefficient of determination error is especially important, because the dispersion of error is an index representing the reliability of the survey: the amount of error caused in processing the data.

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

where ρ_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.

The Table 6 the following findings were obtained:

1) The coefficient of determination error was as small as 1.26%, indicating sufficiently reliable data was obtained from the questionnaire.

2) The largest factor affecting the utilization rate of the Seikan Tunnel was the destination. The farther the destination is from Sapporo, the higher the utilization rate of planes.

3) The availability of the Shinkansen tends to affect the utilization of the Seikan Tunnel. If Tokyo and Sapporo were connected by Shinkansen, the travel would take only 6 hours - 10 hours less than now required.This would cause many people to take the Shinkansen instead of planes, especially because it has not met any accident involving death of passengers, while JAL's jumbo jet crash in 1985 resulted in 524 passenger deaths.

4) Weather also affects the utilization rate of the Seikan Tunnel. During winter Chitose Airport sometimes fails to fully function because of heavy snowfall. The Seikan Tunnel, on the other hand, is little affected by weather, with the Shinkansen having a good reputation for snow countermeasures.

5) In the survey the plane and railroad fares were fixed. The fare is most easily manipulated factor, but it is always relative. Therefore it was assumed that the relative difference between the railway and plane fares would remain the same.

Table-5 Answer tally

Transpor-tation / No.	Railroad ferry	Seikan-Tunnel	Plane	TOTAL
1	16 (7.7)	153 (73.2)	40 (19.1)	209
2	25 (12.1)	148 (71.8)	33 (16.0)	206
3	17 (8.1)	137 (64.9)	57 (27.0)	211
4	9 (4.3)	110 (53.1)	88 (42.5)	207
5	26 (12.2)	51 (23.9)	136 (63.8)	213
6	6 (2.8)	121 (57.3)	84 (39.8)	211
7	1 (1.5)	14 (6.7)	195 (92.9)	210
8	7 (3.4)	119 (58.0)	79 (38.5)	205
TOTAL	107 (6.4)	853 (51.0)	712 (42.6)	1672

Table-6 Results of the variance analysis (Seikan Tunnel)

Factor No.	Factor	Deviation Square	Degree of Freedom	Variance	F-Value	Coefficient of Determination
A	Destination	1964.40	3	654.80	92.72	49.71
B	Weather	639.06	1	639.06	90.49	16.17
C	Existance of Shinkansen	1198.08	1	1198.08	169.64	30.47
E	Purpose of Transport	100.14	1	100.14	14.18	2.38
e	Error	7.06	1	7.06	—	1.26
TOTAL		3908.75	7			100.00

(3) Estimation of Utilization Rate of the Seikan Tunnel Using the Aggregate Logit Model

The data shown in Table 5 represents only 8 examples of the 32 possible. Therefore the data were regressed using the aggregate logit model to form the general model.

$$P = \frac{1}{1 + \exp\,(G(x))}, \quad G(x) = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4,$$

where

P = utilization rate of the Seikan Tunnel
$G(x)$ = utility function
x_1 = destination factor
x_2 = weather factor
x_3 = Shinkansen factor
x_4 = travel purpose factor
$\alpha,\beta_1,\beta_2,\beta_3,\beta_4$ = estimated parameter

The regressive calculation led to the following utility coefficient:

$$G(x) = -1.431 + 0.718x_1 - 0.962x_2 + 1.242x_3 - 0.481x_4 \quad (\gamma^2 = 0.981)$$

In Figure 9-1 the utilization rate of the Seikan Tunnel is shown by destination and presence (or absence) of the Shinkansen, with x_2 = fine and x_4 = business. Figure 9-2, on the other hand, shows the utilization rate of planes similarly obtained. from these figures the following have become clear:

1) The utilization rate of the Seikan Tunnel is affected approximately 15-30% by the presence of the Shinkansen. For example, the rate is 23% when the destination is Tokyo, but only 8%, showing little effect of

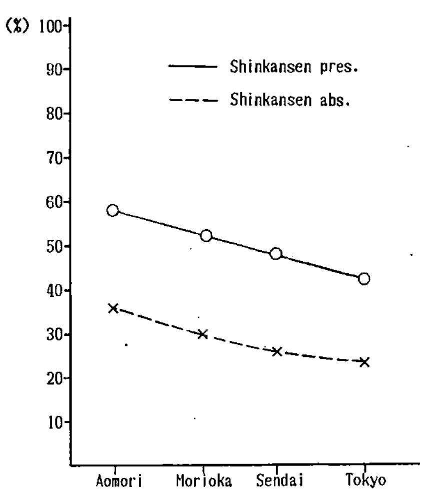


Fig.9-1 Utilization rate of the Shinkansen Tunnel

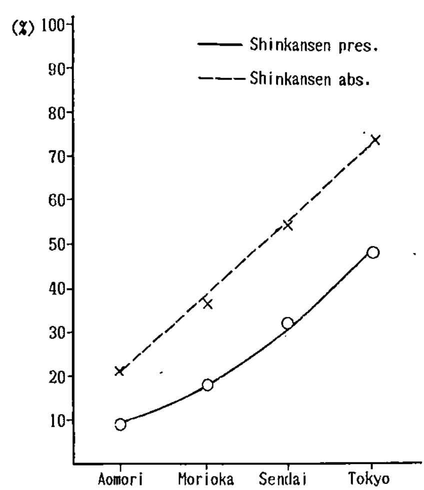


Fig.9-2 Utilization rate of planes

the Seikan Tunnel, in the absence of the Shinkansen. Also, the farther the destination, the lower the utilization rate.

2) The utilization rate of planes exhibits tendency opposite to that of the Seikan Tunnel. It has become clear, therefore, that when the Seikan Tunnel is completed and the Shinkansen extended to Sapporo, many people will choose the railway instead of planes. Even in this case, however, with Tokyo as the destination, the utilization rate of planes is as high as 78%.

3) Weather and travel purpose affect the utilization rate of the Seikan Tunnel approximately 10-20%, and 10-15%, respectively. this shows that completion of the Seikan Tunnel will provide an option to plane passengers.

4. Utilization of Seikan Tunnel for Freight Transport

In order to discuss effective utilization of the Seikan Tunnel, the Japanese Government organized the Seikan Tunnel Affairs Study Group, which carried out a feasibility study of car-train operation in the following three cases:

a) from the Aomori to Hakodate areas using a narrow-gauge railway,
b) from the Nakaoguni to Kikonai areas using a standard-gauge railway,
c) from the Aomori to Hakodate areas using a standard-gauge railway.

The expected advantages and disadvantages of each case are listed below.

a) Between Aomori and Hakodate (ordinary JNR railroad)

1) Only the stations have to be modified, requiring a relatively small investment.
2) The car-train will transport only passenger cars and small-sized (4-ton) trucks.
3) During summer the demand is 4 or 5 times greater than that of other seasons, which may exceed the transport capacity.
4) The transport demand of an average month will result in a deficit operation.

b) Between Nakaoguni and Kikonai (standard gauge)

1) It will be possible to transport all types of cars.
2) It will require a relatively small investment.
3) A large demand is not expected because of the road conditions (especially in Honshu) and the transit time required.

c) Between Aomori and Hakodate (standard gauge)

1) It will be possible to transport all types of cars.
2) A large demand can be expected because the required time will be relatively short.
3) A large investment will be required.
4) This configuration can be adapted for future by the Shinkansen.

The utilization of the Seikan Tunnel by the car-train makes the tunnel something more than a mere railroad facility, putting it beyond the experience of either the Transportation or Construction Ministries. The most practical way of utilizing the tunnel will be to lay a standard-gauge railway between Aomori and Hakodate, preparing for the future initiation of the

Shinkansen. But this also involves some problems: it is very difficult to estimate the increased utilization rate (if any) of the tunnel by the car-train operation, and the amount of compensation to be paid to the existing ferry operation. It is clear that the operation of car-train will seriously damage the Seikan ferry operation - the compensation talks will not be concluded easily. Moreover, a large compensation may seriously affect the financing plan of the car-train service.

The relationship between the expense and time required for freight transport between Sapporo and Tokyo is shown in Fig. 10. It is clear that transport by air takes only 10 hours but is very expensive, while car-ferry transport is cheaper but takes more than 20 hours. The car-train system through the Seikan Tunnel will take 10 - 20 hours and will cost about the same as car-ferry, showing that the construction of the Seikan Tunnel will have a significant impact on goods distribution.

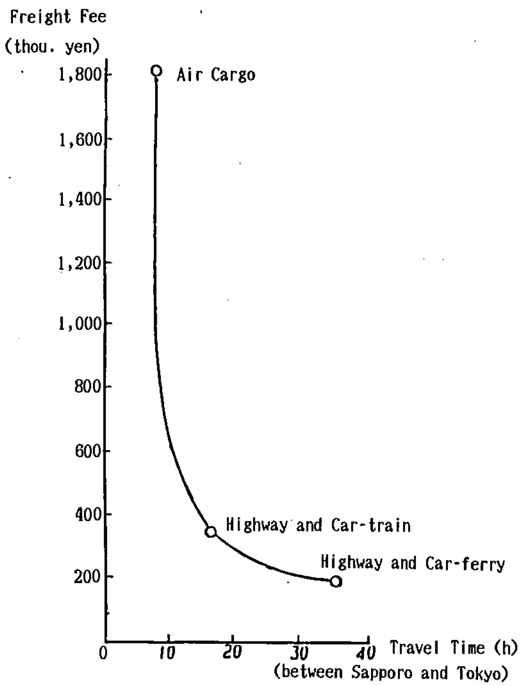


Fig.10 Relationship between the expense and time required for freight transport

ACKNOWLEDGEMENTS

We would like to express our appreciation for the cooperation given by the following: Japan Railway Construction Public Corp. Sapporo Office, Seikan Construction Bureau, Japan National Railway Hokkaido General Bureau, Hokkaido Prefectural Office, and Hakodate Municipal Office. We would also like to express our thanks to the students at Department of Traffic Planning Studies, Faculty of Civil Engineering, Hokkaido University, for their cooperation with the passenger survey.

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