INVESTMENT CRITERIA FOR THE IMPROVEMENT OF SERVICE LEVEL IN JAPANESE URBAN RAILWAYS

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abstract: Private railway operators in Tokyo and Osaka areas have invested in their railway facilities in order to improve and develop their existing railway network. These projects are not so attractive for operators because of the fare regulation and the low elasticity of the demand which results from their regional monopoly. This study proposes the hypothesis of operators' behavior, and finds the investment criteria of railway operators by theoretical and empirical approaches, and proves them from the actual and detailed data of many urban private operators and their projects for these thirty years.

1. INTRODUCTION

Commuter railways have large share of total passenger transport in Japanese large cities. These railways can be classified mainly in three groups: JR, Subways and Private railway companies. The JRs are *private* railway companies whose origin is Japan National Railways. Subways are managed by public railway companies under control of local governments. Private railway companies are pure private sector and they manage their service with little financial support from governments. One of the characteristics of railway transport in Japanese large cities is that private sector has a huge role of passenger railway service. They manage their service on commercial base.

The urban private railway network in Japanese large cities developed at the beginning of 20th century, same as in most countries, and the network was mostly completed before 1930. In these decades, the foundation of the urban private railways was settled. However, at that time the traffic volume was very low and service and facilities of the private railways were rather primitive, for example, rolling stocks of some of the railways were not rapid transit but street car type. The present style of the private railways were completed not by the expansion of the network in 1920s but by the improvement and development of the existing railway systems in these thirty years with the rapid increase of population. Each operator has carried out a large scale of investment for increasing its level of service; increasing capacity, relieving congestion of the terminals, rising speed, improving safety etc.. These improvement projects were / are planned and launched by each private company with less governmental support.

Present study focuses on investment in the railway facilities by the private railway operators in Japanese large cities in these thirty years which make the present style of the railway systems and explain the operators' investment criteria of improvement projects based on the theoretical and empirical analysis. Although the quality of the urban railways has been improved, the railway companies including private operators should continue to improve the level of service, particularly relieving congestion in peak time, on commercial base or, if needed, with governmental support. The study will be able to suggest how we should develop the quality and quantity of the urban railway systems in future.

2. SITUATION OF URBAN RAILWAY COMPANIES

The railway operators which this study deals with do not have large motivation to the improvement projects for their existing lines because of the railway regulatory framework and the transport market situation.

- ◆The improvement of LOS (Level Of Service) do not connect to the increase of demand and profit at least in short term. The railways have already occupied a monopolistic share of commuter trips of their own franchising operation areas for a long time. This means that the demand is somewhat non-elastic in terms of the improvement of the existing network.
- ◆Raising funds for improvement projects is not easy for private operators. The fare is regulated so that it can compensate for their supply cost and pre-determined *reasonable* profit. Operators are not able to put the monopolistic fare and, as a rule, they can not save their profit for investment in advance. Loan is the only available fund for their projects.
- ◆Even if their projects are profitable ones, operators hesitate to launch large projects because of the difficulty of raising fund and the risks for delay for completing projects.

In these difficult situations for investment, various measures have been carried out for increasing quantity and quality by each private operator's decision. What can push operators to invest in their projects for improving LOS ? To deal with this problem, the authors propose the basic concept of behavioral criteria in these situation such as monopolistic operators' decision making for their projects under break-even fare regulation.

3. BASIC CONCEPT OF THE ANALYSIS

The railway companies also manage multiple business (department stores, real estate business, some amusement parks etc.). Their multiple business is very important for their management because its net profit is of the same order as that from railway business. If they make light of investment in railway facilities and become notorious for their low service level, they will lose their confidence and they will lose their profit from their multiple business which are in competitive market even if the profit from railway business do not decrease. This means that maintaining their reputation in railway divisions will connect to keep and increase their total profit and they will make effort to satisfy "*social pressure*" from railway passengers.

Therefore, the following hypothesis which represents basic concept of investment criteria for improvement projects can be proposed under following assumptions.

Assumptions

◆Railway operators themselves plan and launch their projects.
◆The investment which this study deals with is improvement projects for existing lines.
◆The demand is non-elastic in terms of improvement of existing network.
◆The fund for improvement is operators' revenue only from their ticket sales.
◆Railway operators have to obey break-even fare regulation.

Hypothesis of railway operators' basic concept for investment

Railway operators decide to launch improvement projects within the scale which satisfy the following two kinds of contrary *social pressure* and break-even fare constraint.

◆Pressure for better quality of transport
◆Pressure for less expensive fare

Obviously, the former pressure pushes operators for investment, and the latter restrains.

The study proposes two approaches to explain the investment criteria from the hypothesis and focuses on following two indices which represent the two kinds of pressure in the hypothesis.

1) Indices of level-of-service, showing the pressure for better quality of transport.
2) Indices of fare level and its increase, showing the pressure for less expensive fare.

The approach in chapter 4 is finding the investment criteria theoretically from the hypothesis. Chapter 5 is empirical approach. The authors calculate these indices in the case of 10 companies in Tokyo and Osaka areas from the actual data and find the criteria. Then, the authors confirm that both criteria, from chapter 4 and 5, are the same results.

4. INVESTMENT CRITERIA THROUGH THEORETICAL APPROACH

4.1 Model Formulation

4.1.1 The Basic Concept and Valuables

$c_0 \equiv C(s_1|s_0)$; Cost for investment including interest and subsidy (yen/year).
$f_1 \equiv F(f_0, c_0, D)$; Fare level per km after investment (yen/km).
$u \equiv U(s, f)$; Utility of passenger

where

u_0, u_1 ; Utility of passenger before and after improvement projects.
s_0, s_1 ; Service level before and after improvement projects.
f_0, f_1 ; Fare level before and after improvement projects.
D ; Traffic demand (passenger km / year).

Now the hypothesis of operators' behavior stated in chapter 3 can be written as follows.

Operators receive the pressure $u_1-u_0 \geqq 0$ from passenger and also operators will decide their scale of investment satisfying the pressure and break-even regulation of fare.

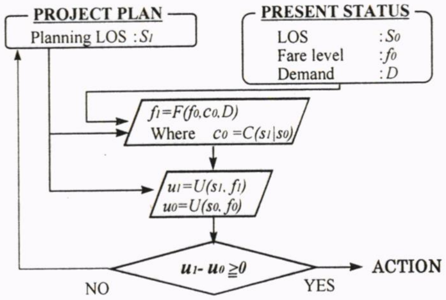

Figure 1. Flowchart of the decision making process of railway operators

4.1.2 Basic Assumptions

◆Cost function of investment ; $c_0 \equiv C(s_1|s_0)$

c_0 is defined as the actual cost for investment which certain operator pays per year. This c_0 includes interest of loan and financial support from governments. In this cost function, it is assumed that the cost is proportional to the increase of LOS, and that marginal cost gets higher as the increase of LOS.

$$\frac{\partial c}{\partial s} > 0 \ , \ \frac{\partial^2 c}{\partial s^2} > 0 \qquad (1)$$

◆Fare function; $f_1 \equiv F(f_0, c_0, D)$ (This represents the break-even condition of fare regulation.)

Fare f is defined as the fare per passenger kilometer. The cost c_0 is assumed to be covered from increase of fare.

$$f_1 = f_0 + c_0/D \qquad (2)$$

Assuming that demand is not elastic and supposing that D is not changeable, then equation (3) is derived from equation (1), (2).

$$\frac{\partial f}{\partial s} > 0 \ , \ \frac{\partial^2 f}{\partial s^2} > 0 \qquad (3)$$

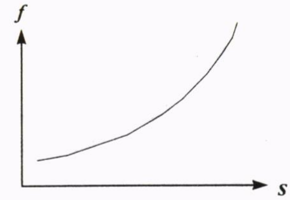

Figure 2. The characteristic of fare function.

◆Utility function of passenger ; $u=U(s,f)$

The characteristic of utility function is shown in figure 3.

It is assumed that the disutility rises in proportion to the increase of fare (for example, the social reluctance to 40% fare increase is more than twice of that to 20% increase), and that the disutility also rises in proportion to the deterioration of LOS. Equation (4) is derived from the assumption shown above.

$$\frac{\partial u}{\partial f}<0\;,\;\frac{\partial^2 u}{\partial f^2}<0\;,\quad \frac{\partial u}{\partial s}>0\;,\;\frac{\partial^2 u}{\partial s^2}<0 \tag{4}$$

Assuming that in the case of the same LOS, the requirement to the improvement of LOS per marginal fare rise will increase in proportion to the fare level (equation (5)).

$$\frac{\partial}{\partial f}\left(-\frac{\partial u/\partial s}{\partial u/\partial f}\right)<0 \tag{5}$$

For instance, in figure 3 , suppose that there are two operators, A and B, whose LOS is the same (s_0) and their fare level is $f_0^A < f_0^B$, and that both operators rise their fare (Δf). Then, the pressure for the improvement of LOS is shown as

$$\Delta s^A \equiv s^A - s_0 < s^B - s_0 \equiv \Delta s^B \tag{6}$$

Equation (6) shows that stronger pressure is put on operator B whose fare level is high. This derives equation (7) and this equation satisfies equation (5).

$$\frac{\Delta f}{\Delta s^A} > \frac{\Delta f}{\Delta s^B} \tag{7}$$

In figure 3, the contours of $U(s,f)$ are drawn as linear, which is not essential.

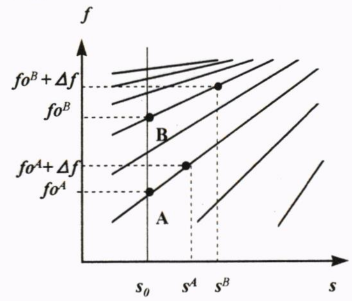

Figure 3. Indifference curve $U(s,f)$

4.2. Derived Investment Criteria of Railway Operators

4.2.1 Investment Criteria of a Certain Operator on *s-f* Plain

The investment criteria of railway operators on the *s-f* plain in which fare function $f_1 = f_0 + c_0/D$ and utility function $U(s,f)$ are drawn is as follows.

In figure 4, an operator which locates at A_0 on *s-f* plain before investment is able to invest where the set satisfies $u_1 - u_0 \geqq 0$ on curve $f_1 = f_0 + c_0/D$. Therefore, the possible domain of investment level is on the bolded allow in figure 4 and the maximum achievement level of service (equal to the maximum scale of investment) is pointed at A_1.

That is, an operator in arbitrary point (s_0, f_0) can invest when equation (8) is satisfied.

$$\left.\frac{\partial F}{\partial s}\right|_{s_0,f_0} < -\left.\frac{\partial u/\partial s}{\partial u/\partial f}\right|_{s_0,f_0} \tag{8}$$

The following two conditions, $U(s,f)=U(s^*,f^*)$ and $f^*=f_0+C(s^*|s_0)/D$, decide the maximum achievable LOS; $max(s_1)=s^*$ and the possible maximum fare level; $max(f_1)=f^*$, that is,

$$s_0 \leqq s_1 \leqq s^* \;,\; f_0 \leqq f_1 \leqq f^* \tag{9}$$

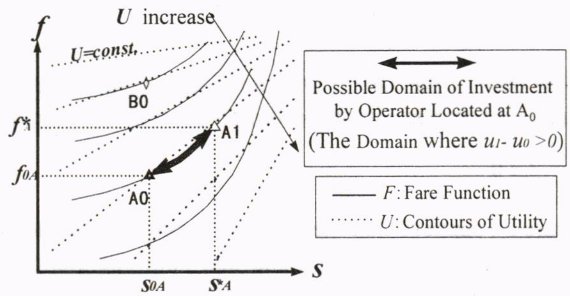

Figure 4. The possible domain of investment

An operator locates at B_0, for example, is not able to invest any more because of the following condition.

$$\frac{\partial F}{\partial s} = -\frac{\partial u / \partial s}{\partial u / \partial f} \tag{10}$$

4.2.2 Investment Criteria in Constant f_0

We will consider the case that the group of operators whose fare level is the same f_0 and compare two operators, A and B, and each service level is different (Figure 5).

In this case, the possible domain of investment is on the bolded allow in figure 5, and the maximum fare level after investment is apparently $f^{*A} > f^{*B}$. Therefore, equations (11) and figure 5,6 are derived.

$$\begin{aligned} \Delta f^{*A} &\equiv f^{*A} - f_0 > f^{*B} - f_0 \equiv \Delta f^{*B} \\ \Delta s^{*A} &\equiv s^{*A} - s_0 > s^{*B} - s_0 \equiv \Delta s^{*B} \end{aligned} \tag{11}$$

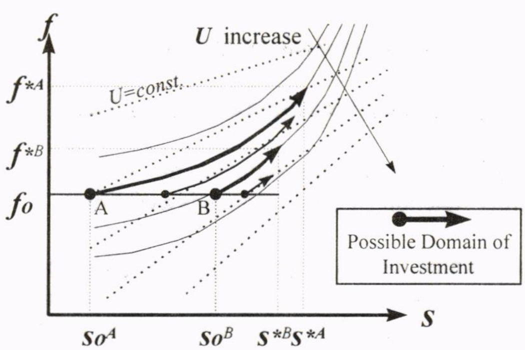

Figure 5. Possible domain of investment by operators A, B on s-f plain

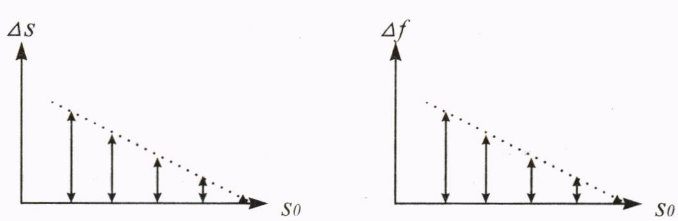

Figure 6. Possible domain of investment by operators A, B on s_0- Δs, s_0- Δf plain

From the part shown above, the investment criteria of railway operators can be said as follows.

Railway operators whose present LOS are lower will be possible to invest their projects with higher LOS and higher fare increase.

4.2.3 Investment criteria in constant s_0

We will consider the case that the group of operators whose level of service is the same s_0 and compare two operators, A and B, and each fare level is different (Figure 7).

In this case, the possible domain of investment is on the bolded allow in figure 7, and the maximum LOS after investment (s^*) is apparently $s^{*A} > s^{*B}$. Therefore, equations (12) and figure 7,8 are derived.

$$\Delta f^{*A} \equiv f^{*A} - f_0 > f^{*B} - f_0 \equiv \Delta f^{*B}$$
$$\Delta s^{*A} \equiv s^{*A} - s_0 > s^{*B} - s_0 \equiv \Delta s^{*B} \quad (12)$$

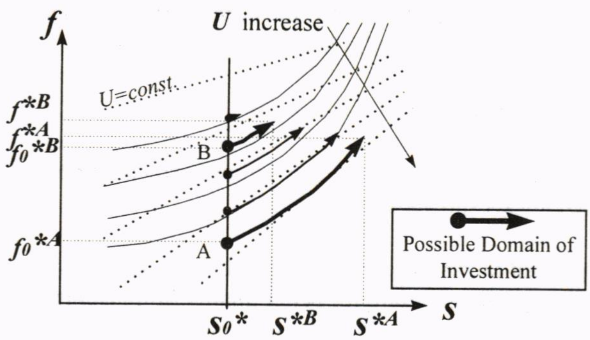

Figure 7. Possible domain of investment by operators A, B on s-f plain

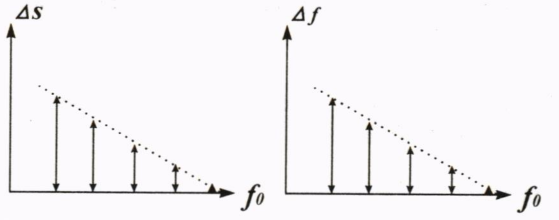

Figure 8. Possible domain of investment by operators A, B on f_0-Δs, f_0-Δf plain

From the part shown above, the investment criteria of railway operators can be said as follows.

Railway operators whose present fare level are lower will be possible to invest their projects with higher LOS and higher fare increase.

5. INVESTMENT CRITERIA THROUGH EMPIRICAL APPROACH

5.1 Cases for the Analysis

This analysis focuses on the following cases.

◆**Operators:** 10 major private companies whose franchise areas are Tokyo and Osaka.
Tokyo and Osaka areas are picked up because they are considered to have nearly same market situation, same share of railway transport, same population density etc.. 10 major private companies which this study deals with have much larger scale of traffic demand compared with other operators and open their financial and LOS data in the same format.

◆**Projects** : Investment in railway facilities in each operator from 1961 to 1991.
These 10 operators have released their plans and actual results of investment in their railway facilities in every year from 1961. Most of these projects are improvement and development of the existing network and construction of new lines which relieve congestion of the existing network. This study does not deal with their investments in their multiple business (developing large scale of residential area, expanding department store chain etc..). The account of railway division is legally divided from other multiple business, therefore, it can be assumed that the criteria of investment for railway facilities have little relation to that in their multiple business.

5.2 Calculation of Indices

The authors also focus on following three indices which represent the two kinds of pressure in the hypothesis shown in chapter 3.

1) L^i_t ; Average load factor in peak time in the busiest section in company i at year t. (%)
(showing the pressure for better quality of transport)
2) f^i_t ; Fare level per passenger kilometer in company i at t. (yen/km)
(showing the pressure for less expensive fare)
3) c^i_t ; Annual expenditure for investment per passenger kilometer in company i at t.
(showing the pressure for less expensive fare) (yen/km)

In the following chapter, these indices are calculated in the case of 10 private companies in Tokyo and Osaka areas from their actual data.

5.2.1 Indices of LOS

There are lots of measures for improving LOS such as more frequent service, extension of trains, speed up, more air-conditioned vehicles, convenient transfer etc.. In this study, the focus is on the following indices as the operators' LOS from actual statistics.

L^i_t ; Average load factor in peak time in the busiest section in company i at t (%).
Load factor is the percentage of passengers per capacity of vehicle. The capacity includes number of seats and number of standing passengers (3 persons per 1m^2)

L^i_t can represent LOS of railway operators because approximately 20 to 30% of the passengers pass through in peak time in the busiest section.

5.2.2 Indices of Fare Level and Its Increase

Following two indices are defined.

f^i_t ; Fare level per passenger kilometer in company i at t. (yen/km)

$$f^i_t \equiv RV^i / D^i_t \tag{13}$$

c^i_t ; Annual expenditure for investment per passenger kilometer in company i at t. (yen/km)

$$c^i_t \equiv C^i_t / D^i_t \tag{14}$$

where

RV^i ; Total revenue in railway division of company i at t.

D^i_t ; Total passenger kilometer of company i at t.

C^i_t ; Total expenditure for investment in railway facilities of company i at t includes interest of loan and governmental support.

Assumptions for calculating C^i_t is as follows.

C^i_t is defined as

$$C^i_t \equiv R^i_t + S_{in}{}^i_t - S_{out}{}^i_t \tag{15}$$

where

R^i_t ; Annual repayment of company i at t.

$S_{in}{}^i_t$; Annual 'deposit' put aside for projects of company i at t.

$S_{out}{}^i_t$; Annual 'deposit' withdrawal from the accumulated deposit of company i at t.

1) R^i_t is calculated from the data of each company's actual cost of its projects at t-1. The amount of total loan at t is assumed to be the amount deducting 'deposit' at t-1 and net revenue at t-1 from company's actual cost of its projects at t-1.
2) In 'deposit system', operators can put aside of fare revenue as the 'deposit' in advance to the opening from their fare revenue at maximum half of the total amount of operators' annual revenue. After opening year they have to withdraw the deposit evenly for 10 years. This system is applied from 1987.
3) In this calculation, railway operators are assumed to borrow the actual amount at t from following the first and the second loan system and to get the rest of total loan at t from the third condition.
   - ◆Interest supply system from Japan Railway Construction Public Corporation

     This system is applied to large scale projects from 1972. Operators repay the same amount of money including interest for 25 years from the opening year of the projects. In this case, the interest which exceeds its rate of 5.0 % are supplied from governments.
   - ◆Low interest loan from Japan Development Bank

     This system is applied to the most of the railway projects. The bank finances to certain pre-determined percentage of the total amount of the project cost. Operators are assumed to repay the same amount from principal and to do its interest for 20 years from the next year of the borrowing. The actual interest rate is applied to this calculation.
   - ◆Loan from city bank

     Operators are assumed to repay the same amount from principal and to do its interest for 10 years from the next year of the borrowing. The actual interest rate is applied to this calculation.

The authors calculate the repayment of the three systems shown above in all years from 1961 to 1991 in each company. R^i_t is the sum of each year's repayment of company i at t.

4) The data of the amount of loan before 1961 is not available. The authors assume the repayment of the loans which are borrowed in before 1961 as follows. The amount of R^i_{61} is assumed to be same as that of interest and depreciation of company i at t. The repayment of the loan after 1962 which are borrowed before 1961 (defined as $R_{61}{}^i_t$) is assumed as

$$R_{61}{}^i_t = R^i_{61} - (t-61) * R^i_{61} / 20 \qquad (61 \leqq t \leqq 80) \tag{16}$$

5.3 Results of the Analysis

This chapter analyzes the investment criteria of urban railway operators applying the indices in 10 companies from 1961 to 1991 shown in section 5.2. In this analysis, the indices concerning fare are converted into real price by the Consumer Price Index (1994 base).

5.3.1 Basic Analysis: Relation Between Improvement of LOS and Fare Increase

Index which represents 'improvement of LOS' is defined as follows.

ΔL^i_t ; Difference of load factor in peak time during 5 years.

$$\Delta L^i_t \equiv L^i_{t-5} - L^i_t \qquad (t=91,86,81,76,71,66) \tag{17}$$

Index which represents ' fare increase' is defined as follows.

r^i_t ; Fare increase rate (real) during 5 years brought from investment.

$$r^i_t \equiv (C^i_t - C^i_{t-5})_{94} / RV_{94}{}^i_t \qquad (t=91,86,81,76,71,66) \tag{18}$$

(The valuables with $_{94}$ are converted into real price in 1994.)

The result is shown at figure 9.

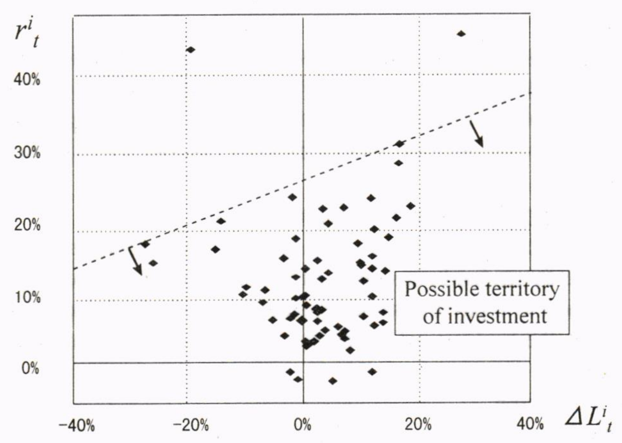

Figure 9. Relation between improvement of load factor and fare increase

In figure 9, positive territory in horizontal axis means the cases where the congestion in peak time are relieved during 5 years. This figure shows that the more the improvement of LOS is, the higher the fare increase rate is. In addition, the dotted line on maximum r^i_t points in certain number of ΔL^i_t can be drawn and this means that the territory under the dotted line represents where railway operators are able to invest.

That is to say,

Operators have invested more money in their projects with more decreasing their load factor.

Therefore, the following proposition can be derived.

Operators will decide their investment scale recognizing that higher fare increase will be accepted in the project with more improvement of LOS.

5.3.2 Relation Between LOS before Investment and Fare Increase / Improvement of LOS

Index which represents 'LOS before investment' is defined as follows.

L^i_t ; Average load factor in peak time in the busiest section in company *i* at *t*. *(t=91,86,81,76,71,66)*

Indices which represent 'fare increase' and 'improvement of LOS' are defined as follows respectively.

Δc^i_t ; The amount of fare increase during 5 years brought from investment.

$$\Delta c^i_t \equiv (C^i_t - C^i_{t-5})_{94} / D^i_t \quad (t=91,86,81,76,71,66) \tag{19}$$

(The valuables with $_{94}$ are converted into real price in 1994.)

ΔL^i_t ; Difference of *load factor* in peak time during 5 years.(from equation (17))

$$\Delta L^i_t \equiv L^i_{t-5} - L^i_t \; (t=91,86,81,76,71,66)$$

The result is shown at figure 10 and 11 .

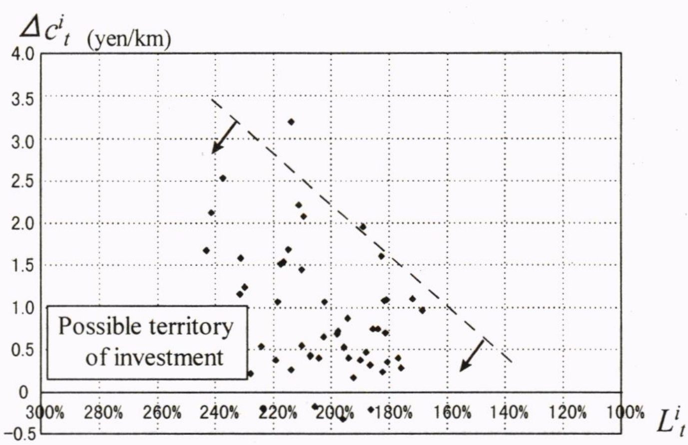

Figure 10. The relation between load factor before investment and fare increase

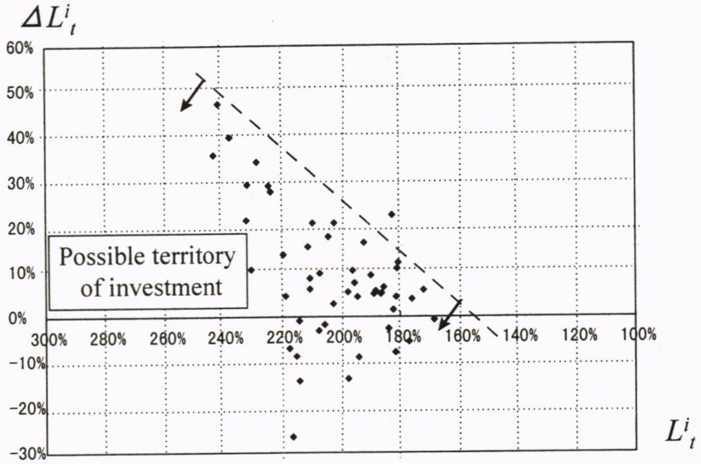

Figure 11. The relation between load factor before investment and improvement of load factor

These figure also show the territories under the dotted lines where projects have been launched. The lower the LOS before investment is, the higher the maximum fare increase is, and the so is maximum increase of LOS.

That is to say,

Operators whose load factors are larger have invested in their projects with more decreasing their load factor and with higher fare increase.

This result is same as the proposition in 4.2.2 and the possible territory of investment in figure 6 is same as that in figure 10,11. Therefore, the proposition in 4.2.2 as follows is demonstrated in this section.

Railway operators whose present LOS are lower will be possible to invest their projects with higher LOS and higher fare increase.

5.3.3 Relation Between Fare Level before Investment and Fare Increase / Improvement of LOS

Index which represents 'fare level' is defined as follows.

f^i_t ; Fare level per passenger kilometer in company i at t. (yen/km)
(t=91,86,81,76,71,66)

Indices which represent 'fare increase' and 'improvement of LOS' are defined as follows respectively.

Δc^i_t ; The amount of fare increase during 5 years brought from investment.(from equation (19))

ΔL^i_t ; Difference of load factor in peak time during 5 years.(from equation (17))

The result is shown at figure 12 and 13.

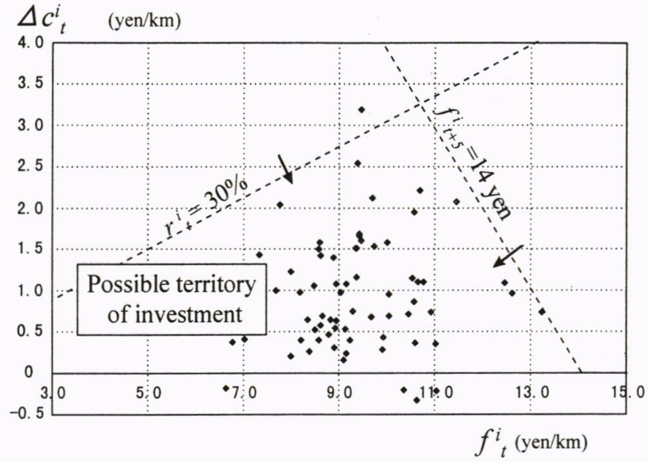

Figure 12. The relation between fare level before investment and fare increase

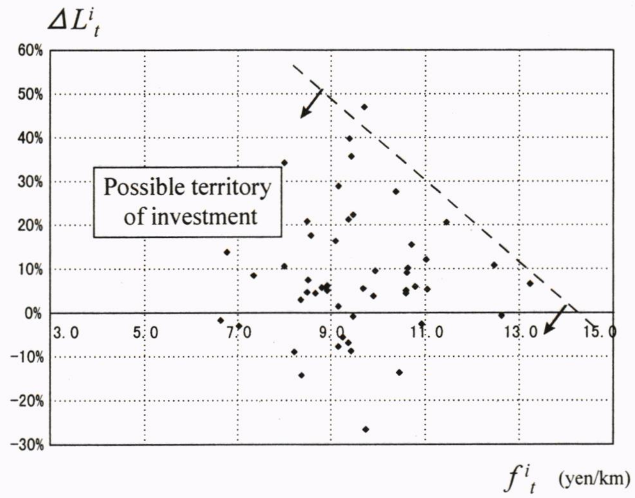

Figure 13. The relation between fare level before investment and improvement of load factor

These figure also show the territories under the dotted lines where projects have been launched. The lower the fare level before investment is, the higher the fare increase and the increase of LOS is. In addition, figure 12 shows that there are two kinds of maximum limits of fare indices, one is the amount of fare level after investment, the other is fare increase rate. Maximum fare level after investment is approximately 14 yen/km and maximum fare increase rate is approximately 30% per 5 years. These limits are considered as passengers' acceptable fare level which railway operators recognize as *social pressure*. This suggests that the large scale projects have been restrained.

The result in this section is summarized as follows.

> *Operators whose fare level are higher have invested in their projects with more decreasing their load factor and with higher fare increase.*

This result is same as the proposition in 4.2.3 and the possible territory of investment in figure 8 is same as that in figure 12,13. Therefore, the proposition in 4.2.3 as follows is demonstrated in this section.

Railway operators whose present fare level are lower will be possible to invest their projects with higher LOS and higher fare level.

6. SUMMARIES AND FURTHER STUDY

This study focused on the behavior of railway operators in Japanese large cities about their investment. The authors proposed the basic concept of behavioral criteria of the railway operators which have monopolistic market under the break-even fare regulation and explained their criteria on improvement of their railway facilities from the hypothesis that

Railway operators decide to launch improvement projects within the scale which satisfy the following two kinds of contrary social pressure and break-even fare constraint.

◆*Pressure for better quality of transport*

◆*Pressure for less expensive fare*

Then, from theoretical and empirical approaches (in chapter 4 and chapter 5 respectively) based on the hypothesis, the same investment criteria of railway operators are derived.

1) Railway operators whose present LOS are lower will be possible to invest their projects with higher LOS and higher fare level.

2) Railway operators whose present fare level are lower will be possible to invest their projects with higher LOS and higher fare level. In the Japanese urban railways' case, from chapter 5, the possible maximum fare increase rate is approximately 30 % per 5 years and acceptable fare level is 14 yen per kilometer (1994 price).

This study, in empirical part (chapter 5), uses 'load factor in peak time (L^i_t) as the LOS index of railway operators. Indeed L^i_t is the most remarkable index of LOS, however, it is just one of the indices which represent railway service. This will be the reason why some of the samples (operators) in the results of chapter 5 do not meet the results in theoretical part (chapter 4). In our further study, authors will propose more generalized index of LOS and demonstrate our hypothesis more clearly in empirical part.

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