BASIC ANALYSIS OF DEMAND AND COST STRUCTURE OF PUBLIC ROAD TRANSPORT SYSTEM IN JAPAN ~CASE OF SUBURBAN BUS TRANSPORT~

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abstract : This paper focuses especially on bus transport in suburban area of large cities in Japan and aims at following points. (1)To clarify the demand and cost structures of the suburban bus transport and develop a Bus Management Model including a demand and a cost functions. (2)To analyze management behaviors of bus operators by applying the model to actual situations. (3)To discuss possible road public transport policies to be introduced. This paper is regarded as a basic study to reconsider the future role of public road transport and the future course of public road transport policies.

1. INTRODUCTION

In Japan, some need for public road transport has existed, both in large and small cities. Because social problems of road traffic congestion and air pollution have recently occurred in many cities with the spread of motorization across the whole country, road public transport is required to contribute to reduce the road traffic volume from viewpoints of both effective use of the limited space in cities and the regional and global environment protection, as well as to improve the mobility for people. However, it is forecasted that the financial expenditure for the improvement of transport facilities and services may decrease in the future because the funding will be diverted to other matters such as the social welfare required by the future aging society. In addition, management condition of public road transport operators may become more difficult due to the continued spread of motorization. Therefore, we should reconsider what can be expected of public road transport under the actual and future conditions and what kind of transport policies should be introduced in order to realize it.

This paper focuses especially on the bus transport system, which has played an important role in public road transport market. Firstly the authors develop a Bus Management Model which consists of a Demand Sub-Model and a Cost Sub-Model. Secondly by applying the model to some actual branches of suburban bus operators, the authors analyze the management behaviors of operators under three kinds of strategies such as profit increase, total surplus increase and cost reduction, and finally the authors discuss what kind of public road transport policies should be introduced.[a]

The target area of the analysis is confined to the suburban area in Tokyo metropolitan area, which functions mainly as satellite cities (the residential area for people working in the C.B.D.). Though the public bus transport has played an important role as a feeder transport to railway station in this area with dense population, it has faced the problem that the bus demand tends to decrease. However the authors regard the suburban area of large cities as an important area for future bus industry in Japan because the function of bus transport has been utilized better as the form of the feeder line to railway station in this area.

For the analysis, we selected 7 bus operators (1 public and 6 private) operating in Tokyo suburban area by considering following two points.

(a)Operating area of the selected operators are located within 20-40km from the center of Tokyo. This means the target area of this study is the suburban residential region of large city.

(b)The selected operators varies in the organization type (public and private), operator size (fleet size), financial condition (profit and deficit) and service level (network density and frequency).

The characteristics and locations of selected operators are shown in Table 1 and Figure 1 respectively. It must be noted that bus operators in Japan normally divide their operation area into small districts and arrange a branch office to provide the service in each district. In this paper all analyses are conducted on the basis of 48 bus operator branches owned by selected 7 operators.

Table 1 Characteristics of selected 7 bus operators

Operator	Organization Type	Fleet Size (Vehicles)	Financial Condition	Number of Branches
A	PUBLIC	1005	DEFICIT	12
B	PRIVATE	1946	PROFIT	14
C	PRIVATE	755	PROFIT	11
D	PRIVATE	283	DEFICIT	3
E	PRIVATE	196	DEFICIT	4
F	PRIVATE	102	DEFICIT	3
G	PRIVATE	57	PROFIT	1

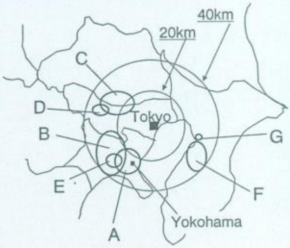


Figure 1 Location of selected 7 bus oprators

2. DEVELOPMENT OF BUS MANAGEMENT MODEL

2.1 Structure of the Bus Management Model

The authors developed a Bus Management Model, which consists of Demand Sub-Model and Cost Sub-Model. Overall structure of the model is shown in the Figure 2. This model outputs operating cost, profit of operators and total surplus produced when an operator provides a particular service of network density and frequency under an environmental parameter (Population Density) and characteristics of operators (Operation Area, Wage and Fare).

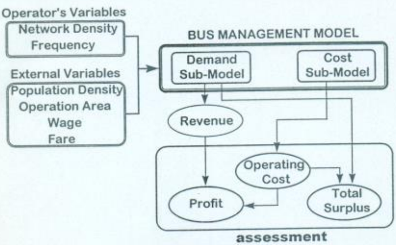


Figure 2 Overall strucutre of Bus Management Model

This model is based on following assumptions on circumstances introduced to simplify the model practically.

(a) Socio-economic characteristics of residents in the target area are homogeneous.

(b)In one operation area, the service (network density and frequency) is uniformly provided.

(c)Each branch is a single provider of bus service.(However this does not mean the bus industry is monopolistically operated, because it faces quite tough competition against the personal transport means.)

It is assumed that the operator can control only two variables of network density and frequency which also represent the level of service and that the size of operation area and fare are given as external variables. This is mainly because in Japan bus operators can not enter into or exit out of the market, and can not change their fare level without the governmental authorization , according to the regulation of bus industry.

2.2 Formulation and Estimation of Demand and Cost Sub-Models

2.2.1 Demand Sub-Model

The Demand Sub-Model estimates the revenue which a branch can gain by providing a certain level of service. This sub-model has two steps. Firstly, trip density is calculated by a macroscopic demand function (1), and secondly, revenue is calculated by a function (2). Each step is formulated as follows[b)c)]:

$$Td = f\,(Pd, Nd, Fr) \quad \text{----------(1)}$$

$$R = Td \cdot Oa \cdot Fa \quad \text{----------(2)}$$

where,

Td	:Trip Density (trips/km^2/year)
Pd	:Population Density (persons/km^2)
Nd	:Network Density (km/km^2)
Fr	:Frequency (services/direction/day)
R	:Revenue (Yen/year)
Oa	:Size of Operation Area (km^2)
Fa	:Fare (Yen/trip)

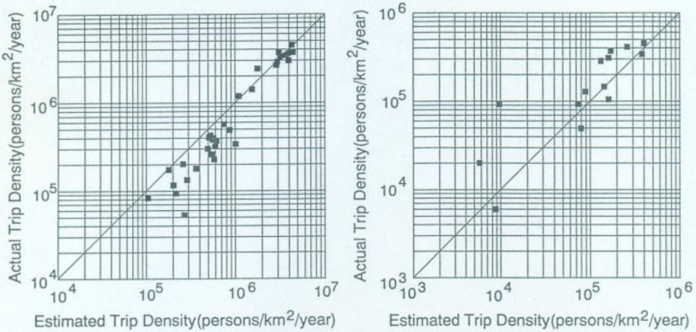
We applied above function (1) to actual transport data acquired through some original surveys by the authors, in order to estimate the unknown functions f(·) for trip density. The result is :

$$Td = 3.09 \cdot 10^{4} \cdot Pd \cdot (1\text{-}\exp(-4.71 \cdot 10^{-5} \cdot Nd^{0.68} \cdot Fr^{0.86})) \qquad r=0.956 \quad \text{--------(3)}$$

The estimated trip density function leads to two conclusions. Firstly, trip density produced in each area is proportional to its population density, and the marginal trip density decreases as both network density and frequency increase. Secondly, the elasticity of frequency for demand is larger than that of network density, comparing the power of frequency with that of network density. This means the frequent service is preferable to the dense network service for users in the target area.

On the other hand, fare level is not introduced into trip density function, because it does not vary so much among the selected operators in the target area. Fare (Fa) of each branch used in the function (2) is calculated by dividing the revenue by the total number of users, and varies from ¥112 to ¥245, which is related to the initial fare rate and the average trip distance. At the stage of formulation and estimation, other factors such as railway network density were also considered, however introduction of them had no effect on the improvement of its precision.

Figure 3 shows the variation between estimated trip densities and actual trip densities. In these figures, branches with relatively dense population tend to have larger estimated value than actual one, while opposite result can be observed in the case of branches with relatively thin population. Therefore this trip density function should include another factors of demand related to the population density such as the road traffic congestion.



CASE 1 Dense Population Branches
(Population Density ≧ 4000 persons/km²)

CASE 2 Thin Population Branches
(Population Density < 4000 persons/km²)

Figure 3 Fitness check of Trip Density Function

2.2.2 Cost Sub-Model

The Cost Sub-Model outputs an operating cost of each branch when it provides a certain level of service. Considering the basic deterministic factors of operating cost, following functions are derived.[d,e,f,g]

$$Fl = g\,(Vk, Pd) \quad \text{----------------(4)}$$

where,

$$Vk = 2Nd \cdot Oa \cdot Fr \quad \text{-----(5)}$$

$$C = h\,(Fl, W) \quad \text{-----------------(6)}$$

where,

Fl	:Fleet Size (vehicles)
Vk	:Vehicle Kilometers (km/day)
Pd	:Population Density (persons/km²)
Nd	:Network Density (km/km²)
Oa	:Size of Operation Area (km²)
Fr	:Frequency (services/direction/day)
C	:Operating Cost (Yen/year)
W	:Wage (Yen/month/person)

This Sub-Model has two steps. Firstly, the fleet size owned by each bus operator is determined by the function(4) and (5). Then the operating cost is calculated by the function (6). The fleet size is proportional to the vehicle kilometers, and is also depends on the driving speed which may be affected by road traffic situations. The vehicle kilometers can be calculated by the function (5) as the product of operation kilometers and frequency, and the operation kilometers is the product of network density and size of operation area. Operating speed is represented by the population density as shown in the function (4), under the assumption that there is an interrelation between the population density and the driving speed (higher driving speed can be attained in an area with lower population density).

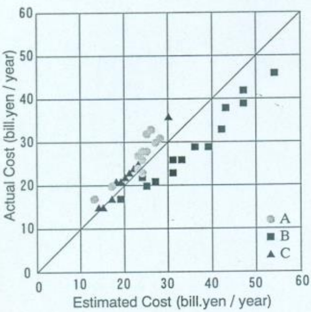
On the other hand, in the bus industry, personnel cost accounts for large part (about 60-70%)[h)] of total operating cost as it is said to be labor-intensive. Therefore the operating cost is expected to be approximately proportional to the size of staffs and the wage level. In this model, it is assumed that the size of staffs is explained by the fleet size as shown in the function (6).

Unknown functions g($\cdot$) for fleet size and h($\cdot$) for operating cost were estimated as follows by applying the data mentioned earlier. The results are:

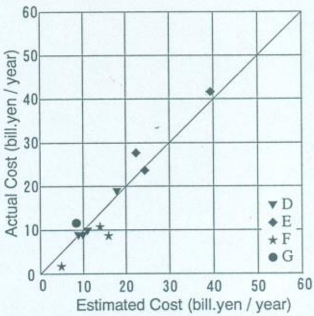
$$Fl = 0.0092 \cdot (Nd \cdot Oa \cdot Fr) \cdot Pd^{0.076} \quad r=0.984 \quad \text{----------(7)}$$
$$C = 79.3 \cdot W \cdot Fl^{0.84} \quad r=0.958 \quad \text{----------(8)}$$

From above two functions, following points are concluded. Firstly the driving speed represented by the population density have a definite influence on the fleet size. Secondly the power of fleet size (Fl) suggests that slight scale of economy exists in the bus industry.

Figure 4 illustrates two cases of variation between actual cost and estimated cost, one is for the group consisting of relatively large size operators and the other is for the relatively small size operators, although the same cost functions (7) and (8) can be applied for both. The 45 degree line drawn in both figures means the estimated cost coincides with the actual cost, and this line can be regarded as an average cost line of selected operators in a sense.



(a) Large Operators



(b) Small Operators

Figure 4 Fitness check of Cost Sub-Model

From two figures, it is found that there is a clear difference of management efficiency among operators.

In the case of private operator B, which is famous for the enterprising attitude toward the management, the management of every branch is relatively efficient as compared with other operators. In contrast to this, the result of public operator A shows its relative inefficient management. On the other hand, we can not definitely observe the influence of size of operators on the efficiency of their operation after the consideration of difference of wage level, though it is said that the small operators provide their service with the lower cost than the large operators. Therefore it is expected that the low cost operation of small operators are caused by the relatively low wage level.

In the above mentioned cost analysis, the difference of some conditions between private operators and public operator is not considered. However, if considered, it is expected the result will change obviously.

2.3 Method of Calculating Total Surplus

2.3.1 Definition of Total Surplus

The Bus Management Model outputs also total surplus produced by the improvement of level of service. Total surplus in a broad sense includes indirect effects such as environmental cost and road traffic congestion as well as the direct effects such as the reduction of travel time of users and profit increase of operators. However, total surplus is defined in this study for the simplification of calculation as follows.

$$\begin{aligned}\text{Total Surplus} &= \text{User's Surplus} + \text{Operator's Surplus}\\ &= (\text{Service Benefit} - \text{Fare Expense}) + (\text{Fare Income} - \text{Service Cost})\\ &= \text{Service Benefit} - \text{Service Cost} \quad \text{----------(9)}\end{aligned}$$

The increase of service benefit is calculated by the following equation proposed in previous studies.

$$\text{Service Benefit} = \int_{Gc_2}^{Gc_1} D(Gc)\,dGc \qquad \text{----------(10)}$$

where,

D(Gc) :Demand Function

Gc_i :Generalized Cost at stage i

i = 1 :without the improvement of LOS

2 :with the improvement of LOS

According to this method, the amount of service benefit is shown as a shaded area in the figure 5, when the generalized cost decreases by the improvement of level of service. If we introduce an assumption that curve ab is a straight line to simplify the calculation, then the equation (10) is transformed as follows.

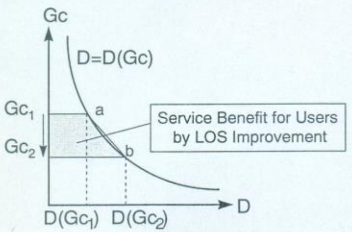


Figure 5 Concept figure for calculation of service benefit

$$\text{Service Benefit} = \{D(Gc_1)+D(Gc_2)\} \cdot (Gc_1-Gc_2) / 2 \quad \text{----------(11)}$$

On the other hand, service cost, which is defined as an amount of the increase of the operating cost, is calculated by the functions (7) and (8) as follows.

$$\begin{aligned}\text{Service Cost} &= C_2 - C_1 \\ &= C(Fl_2, W) - C(Fl_1, W) \quad \text{----------(12)}\end{aligned}$$

where,

C_i	:Operating Cost at stage i (Yen/year)
Fl_i	:Fleet Size at time i (vehicles)
W	:Wage (Yen/month/person)
i = 1	:without the improvement of LOS
2	:with the improvement of LOS

2.3.2 Development of Demand Function

In order to calculate the service benefit, we developed a demand function which is described as a function of the level of service related the generalized cost in monetary terms.

As we mentioned, operators are assumed to control only the network density and the frequency in this study. This means that improving the level of service by operators contributes only to the decrease of access time to the nearest bus stop and waiting time for bus. Therefore the only factor which influences in demand under this condition is a time cost spent before taking a bus, which is defined as a "Total Access Cost" in this paper.

Thus service variables of network density and frequency are transformed to an average access time and an average waiting time respectively by equations (13) and (14) under the following assumptions introduced to simplify the circumstances.

(1)Operating time in a day (H) is 17 hours (a.m.6~p.m.10)

(2)Distribution of bus routes and bus stops in a region is uniform. Interval of neighboring bus stops (Iv) is 400m, considering the actual situation in the study area.

(3)Walking speed of users to bus stops (Vw) is uniformly 4 km/hour.

(4)Time value (Vt) is 2,000 Yen/hour for all residents.[i]

Suppose that a demand catchment area of one bus stop is a circle whose center is a bus stop, the size of this area (S) is calculated as shown in figure 6. Then the average access distance is defined as two thirds of the radius of this circle area, thus average access time can be calculated as follows.

$$\text{Average Access Time (hour)} = \{2/3 \cdot (Iv / \pi / Nd)^{0.5}\} / Vw \quad \text{----------(13)}$$

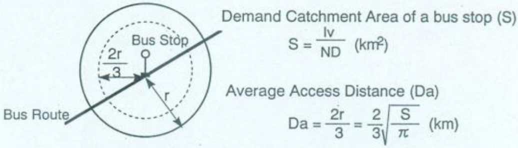


Figure 6 Concept figure for calculation of average access distance

where,

Iv	:Interval of Neighboring Bus Stops (km)
Nd	:Network Density (km/km^2)
Vw	:Walking Speed (km/hour)

On the other hand, average waiting time is defined as a half of time headway of neighboring two buses although in reality the headway does not always proportionally affects the level of service for users.

$$\text{Average Waiting Time (hour)} = H / Fr / 2 \quad \text{----------(14)}$$

where,

H	:Operating Time in a day (hours)
Fr	:Frequency (services/direction/day)

Finally the total access cost is defined as the product of total access time (the sum of access time and waiting time) and value of time. Therefore the total access cost is :

$$Ac = Vt \cdot [2/3 \cdot (Iv / \pi / Nd)^{0.5} / Vw + H / Fr / 2] \quad \text{----------(15)}$$

where,

Ac	:Total Access Cost (Yen/trip)
Vt	:Value of Time (Yen/hour)
Iv	:Interval of neighboring bus stops (km)
Nd	:Network Density (km/km^2)

Then the equation between the demand and the total access cost was estimated as follows.

$$D = 1.39 \cdot 10^9 \cdot Oa \cdot Pd \cdot Ac^{-2.79} \qquad r=0.813 \quad \text{----------(16)}$$

where,

D	:Demand (trips/year)
Oa	:Size of Operation Area (km^2)
Pd	:Population Density ($persons/km^2$)
Ac	:Total Access Cost (Yen/trip)

3. ANALYSIS OF MANAGEMENT BEHAVIORS OF BUS OPERATORS

The Bus Management Model was applied to two actual branches (D1 and B9). Branch D1 belongs to relatively small size private operator operating in western area of Tokyo. Population density of the operating area of branch D1 is about 8,000($persons/km^2$). On the other hand, branch B9 belongs to the largest private bus operator operating in mainly central part of Kanagawa prefecture and its population density is about 3,700($persons/km^2$). In the actual situation, branch B9 provides a relatively higher level of service(network density and frequency) than branch D1 in spite of relatively thin population, because operator B is operating in a very large region including fruitful markets and therefore it is possible for it to compensate for the loss of some branches by the profit of others.

Figure 7 shows contours of profit, total surplus and operating cost for both branches simulated by the model due to the variation of two variables of level of service. An arrow drawn in each contour shows the expected direction of management behavior each operator should adopt when it considers three kinds of strategies such as profit increase, total surplus increase and cost reduction respectively. The base of each arrow is a point of existing level of service defined by the network density and the frequency. The direction of arrow coincides with that of the steepest slope from the point of actual level of service. In real situation, bus operators improve their level of service little by little toward the optimum point for them, because of the following reasons. Firstly operators do not know the optimum level of service and can only forecast a situation that happens when they change the level of service slightly from the present level. Secondly they can not do large investment at a stretch due to the tight financial situation. For these reasons it is natural to assume bus operators try to shift the level of service to most effective direction judged at their present situations, which is the direction with the steepest slope of profit increase, total surplus increase and cost reduction.

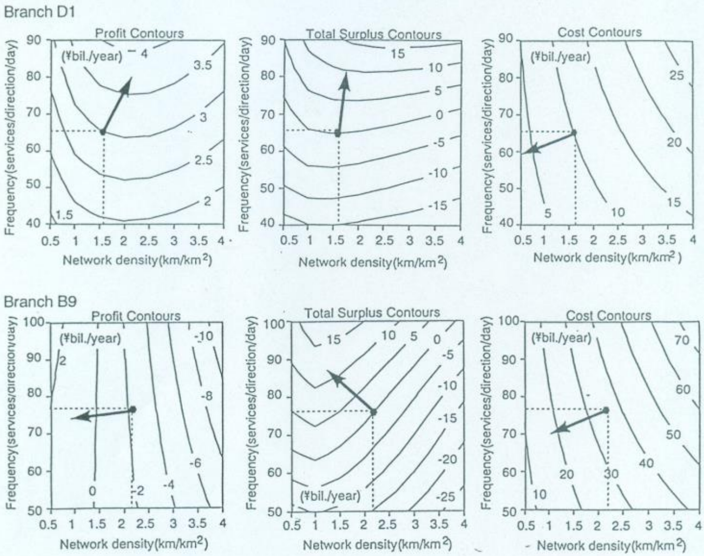


Figure 7 Contours of profit, total surplus and cost for two actual branches.

From the profit contours, we can find that branch D1 is able to make more profit when it increases especially the frequency rather than the network density. This may be derived from the above mentioned conclusion that the elasticity of frequency for the demand is larger than that of network density and therefore the increase of frequency contributes more to the profit increase. In contrast to this, branch D1 must decrease the network density under an almost even frequency, in order to reduce the deficit. These results may suggest the following two points. Firstly, there has been potential demand in the area with relatively dense population like branch D1, therefore operators can make more profit if they improve their level of service. Secondly in the area with relatively thin population like branch B9, operators are apt to have deficit and they can not improve their financial situation without decreasing their level of service. This is mainly because the potential demand is not so large and moreover they must keep some unprofitable lines due to the governmental regulations requiring them to provide with service. Therefore it is forecasted that the bus lines will reduce in this area if the governmental regulations are removed. On the other hand, from the total surplus contours, it can be found that, in the case of branch D1, the arrow of surplus increase points to almost same direction (a little bit more frequency oriented direction) of profit increase. In the case of branch B9, it has to increase the frequency and decrease the network density in order to increase the total surplus. These results show that the increase of frequency has a greater contribution to the increase of total surplus in these two cases.

Recently many bus operators are inclined to be conservative or defensive because they fear falling into the financial difficulties and have pessimistic prospects for the future bus market condition. This leads to their defensive management behaviors of reducing their operation as shown by the arrows in the cost contours (trying to improve the situation by the reducing reproduction policy). However, this analysis found that two types of bus market can be observed in suburban area. Operators can make more profit in fruitful market with relatively dense population in suburban area if they take the positive management behaviors of the increase of their level of service. In addition to this, this positive management behavior also contributes to the increase of total surplus. Therefore it is important to give bus operators in fruitful market some incentives to increase their level of service based on the strategy to make more profit. On the other hand, in the unfruitful area, operators will reduce their service to improve their financial condition if the governmental regulation to keep the unprofitable service is removed. At the same time this behavior causes the keeping of or the decrease of the total surplus though there is a chance to increase the total surplus by improving the level of service. In this unfruitful market, the direction of management behavior of operators based on the profit increase strategy is different from the direction toward the direction of total surplus increase. Therefore it is necessary for a government to control behaviors of operators and to assist the finance of operators, in order to prevent them from reducing their level of service through the reducing reproduction policy, from a view point of increasing the total surplus.

4. CONCLUSIONS

In this study, authors developed the Bus Management Model and analyzed the management behaviors of operators operating in suburban area of large cities. This study concludes with the following points.

(1)The authors developed the macroscopic demand and cost functions which include the network density and the frequency as basic variables and can comprehensively explain the situation of bus operation in suburban area of large cities.

(2)The difference of management efficiency between private operators and public operators and the slight scale of economy in the bus operating cost can be observed.

(3)In the area with dense population, it is possible for some operators to make more profit if they adopt the positive strategy such as the increase of network density and frequency. Moreover this attitude toward the management also contributes to the increase of total surplus. Therefore it is important to give bus operators in fruitful market some incentives to encourage their management based on the profit increase. However it is thought that the operators' behaviors are tend to be conservative enough to incline toward the cost reduction strategy in actual situation because of the weak financial power of operators, regulations to entry into and exit out of the bus market and other regulations for the operation.

(4)On the other hand, in the area with rather thin population even in the suburban area of metropolitan region, operators tend to fall into the deficit, and this causes their defensive management behavior and moreover the keeping of or the decrease of total surplus. Therefore it is necessary for a government to control the operators' behaviors and to assist the finance of operators, in order to keep or increase their level of service, from a view point of the total surplus increase.

Finally, the authors propose that the following points should be considered in further study.

(1)Target area should be extended to cities where the condition of competed transportation means and the qualitative characteristics of demand are different from the suburban area of large cities.

(2)In the case of suburban bus transport, the demand becomes saturated as the increase of level of service. In further study, it is necessary to extend the range of level of services to find its progressive contributions to the demand.

(3)The effect of fare level on the demand and the effect of public financial support (the subsidization system) on the viability of bus operation should be considered.

REFERENCES

a)Jeyandran S., Watanabe R. and Ieda H. (1995) Management Analysis of Public Bus Transport System. **Proceedings of Infrastructure Planning 18th(2)**, 357-360.

b)Douglas N.J. (1984) An Ecometric Investigation into the Demand Function for U.K. Bus Express Coach Travel During a Period of Deregulation. **Transport Research Forum October**, 194-203

c)Brechman J. (1987) Analysis of Costs, Economies of Scale and Factor Demand in Bus Transit. **Journal of Transport Economics and Policy Vol.17(1)**, 1-16

d)De Borger B. (1984) Cost and Productivity in Regional Bus Transportation : Belgium Case Study. **The Journal of Industrial Economics Vol.37(1)**, 35-54

e)Lee D. (1989) Transit Cost and Performance Measurement. **Transport Reviews Vol.9(2)**, 147-170

f)Wabe.S and Coles O.B. (1975) The Short Run and Long Run Cost Function of Bus Transport in Urban Areas. **Journal of Transport Economics and Policy Vol.9**, 127-140

g)Wilson H. (1977) The Cost of Operating Buses in U.S. Cities. **Journal of Transport Economics and Policy Vol.11(1)**, 68-91

h)Japan Bus Association (1994) **Bus Industry in Japan 33th**

i)Shimoishi J., Ieda H. and Tamaishi S. (1987) Stochastic estimation of the value of time on inter-regional passenger transportation. **Proceedings of Infrastructure Planning 11th**, 71-77.