Evaluation of bus route efficiency by network DEA including social priority

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Abstract: Bus management is facing increasingly serious challenges every year, and the execution of efficient bus management is a pressing issue for municipalities and transportation operators. This research performed an analysis of efficiency using a network data envelopment analysis method by using the Tomakomai city bus routes as a model case, with the aim of structuring bus route management from the perspectives of optimizing route arrangement and attracting customers. Regarding the efficiency of route arrangement in particular, this research is characteristic in that it evaluated bus routes taking into account access to hospitals and commercial facilities.

Keywords: Public transportation planning, data envelopment analysis,
network DEA model , bus service, bus route evaluation

1. INTRODUCTION

In recent years, the number of users of public transportation has dropped throughout Japan due to the increasing number of personal vehicles. In particular, bus transportation competes with automobiles and bicycles, and the number of users is on a path of steady decline. Against this background, deregulation of the commuter bus industry was enacted in 2002. As a result, there was concern that the bus service might deteriorate since private operators tend to abolish or reduce the number of services on unprofitable routes.

The subject of this research is a City Bus Service that was operated in Tomakomai city. Due to the decrease in number of users and the enormous burden on public finances, it was decided to assign the bus routes to a private operator, with the expectation that economic performance and efficiency would increase on the management front from 2012. The operator is obliged to maintain the routes and fares as they were at the time of the handover for 3 years, but since the operator has discretion over the continuation of routes thereafter, it is likely that it will withdraw from unprofitable routes in the future. As such, it is important to precisely evaluate the characteristics of the service in the current situation from the perspective of usage, profit, and expenses associated with each bus route, in order to consider the maintenance and upgrade of route buses.

Therefore, in this research, comparative efficiency is evaluated in terms of “route arrangement efficiency” and “service efficiency” by data envelopment analysis (DEA) in order to clarify the service characteristics of each Tomakomai city bus route, such as the status of the route and its ability to attract customers. In particular, because bus services are influenced by various factors, such as the service route, number of bus stops and the population along the route, a network DEA model is used in order to perform a graded analysis of efficiency.

In a study of the evaluation of bus route efficiency, Miyazaki and OH-I evaluate bus services from the perspective of user satisfaction and willingness to pay, but do not perform an evaluation that extends to individual bus routes. Inoi *et al*. (2004) systematize methods for evaluating the effectiveness of community buses, but scheduled buses on fixed routes are not targeted in the analysis. Higashimoto *et al.* (2005) construct a method for evaluating the efficiency of a particular bus route from the perspective of both the operator and users of the bus route, but the inner structure of unprofitable routes is not analyzed.

For considering the properness of subsidies on each route, Takeuci et al. (1991) is a pioneering approach, which is classified bus route into a competitive and sustainable business course and a civil minimum course giving priority to mobility of citizens by using route potential as index. Furthermore, Mizokami et al. (2005) evaluates bus routes by two different aspects, productive efficiency and the possibility of boosting potential demand, however, an evaluation method considering social demand, such as accessibility to hospitals and commerce facilities on bus routes, is not systematized.

Also, in regard to analysis using network DEA, Sekiguchi (2008) takes a semi-public sector urban railway as a corporate entity and uses a network DEA model to evaluate its efficiency while considering the inner structure of the entity, and Ysutsui *et al.*, (2007) analyze an electricity operator.

This research treats the management efficiency of bus routes as a vertically integrated structure composed of route arrangement efficiency and service efficiency, and evaluates individual bus routes using network DEA.

2. THE ISSUE OF BUS TRANSPORTATION IN TOMAKOMAI CITY

Tomakomai City is a regional city with a population of approximately 173,000 people located in south-west Hokkaido. Since its inauguration in 1950, bus transportation has been an important means of transportation comprising a network of routes within Tomakomai City and the surrounding area, and it facilitates daily life in the region. However, as shown in Fig. 1, there has been a substantial drop in the number of users due to automobile-dependent suburbanization. Combined with a reduction in the number of young people, this resulted in suburban bus routes being abolished from 2000, and all routes were privatized in April 2012. The operator is contractually obliged to maintain the current transportation service for 3 years after the transfer, but the standard of bus transportation service from 2015 onwards is left to the discretion of the operator.

Accordingly, the construction of a support system to maintain regional bus routes and the establishment of a method of evaluation for bus routes is an urgent task for Tomakomai City. In particular, with only 2 out of the 23 routes that form the subject of this research operating profitably, there is strong demand for a bus route maintenance system that evaluates whether unprofitable routes should be maintained or abolished not just in Tomakomai, but in other municipalities as well, and the construction of such an evaluation system is of primary importance.

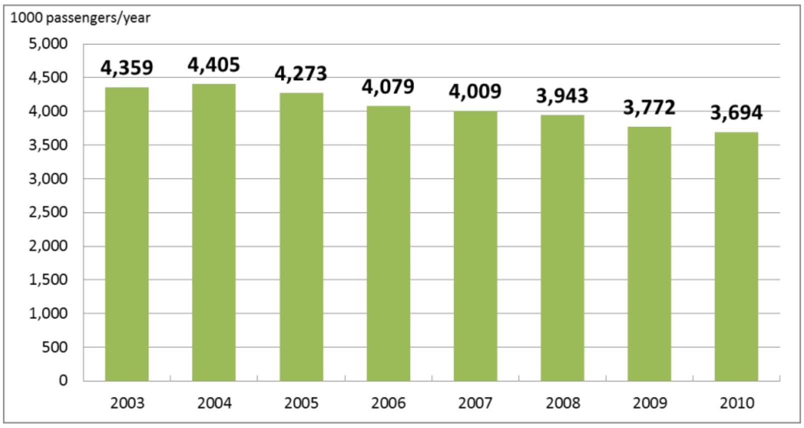

Figure 1. Decline in the number of bus passengers in Tomakomai City

3. CONSTRUCTION OF A METHOD FOR EVALUATING THE EFFICIENCY OF BUS ROUTES BY NETWORK DEA

3.1 Outline of DEA

When examining the activities of an organization, the ratio of resource input to its resulting benefit output, called the input/output ratio, can be used as a measure of resource conversion efficiency. This is a particularly common measure of operational efficiency, using expenditures and revenues as variables; however, using it is difficult with multi-input or multi-output data, and therefore DEA is used as an evaluation method for problems that involve multiple criteria.

As evaluated by DEA, an entity A that produces the highest output from the lowest input is regarded as efficient, and the origin and the entity are connected with a straight line called the efficiency frontier. The efficiency frontier indicates the performance of a superlative entity, and evaluates the performance of other entities on the basis of the efficiency frontier. The efficiency value of entity A is defined as 1.0, allowing other entities to be assigned a relative value. Efficiency evaluation according to DEA is therefore a relative comparison based on the most efficiently performing entity, revealing areas for improvement of inefficient entities.

3.2 Network DEA Model

The most basic DEA model is the Charnes-Cooper-Rhodes (CCR) model. In this model, for decision making unit (DMU)$_j$ $(j = 1, \cdots, n)$, m input values $X = (x_{mj}) \in R^{m \times n}$, and an output value $Y = (y_{sj}) \in R^{s \times n}$, the efficiency of a given evaluation item DMU$_0$ is defined by Equations (1)-(4).

Target function: $\max \theta = \dfrac{u_1 y_{1o} + u_2 y_{2o} + \cdots u_s y_{so}}{v_1 x_{1o} + v_1 x_{1o} + \cdots v_m x_{mo}}$ (1)

Constraint equation: $\dfrac{u_1 y_{1j} + \cdots + u_s y_{sj}}{v_1 x_{1j} + \cdots v_m x_{mj}} \le 1 \; (j = 1, \cdots, n)$ (2)

Input value weight: $v_1, v_2, \cdots, v_m \ge 0$ (3)

Output value weight: $u_1, u_2, \cdots, u_m \ge 0$ (4)

Taking (v^*, u^*) as the optimal solution and the target function value as θ^*, we say that DMU$_0$ is D-efficient if $\theta^* = 1$, and DMU$_0$ is D-inefficient if $\theta^* < 1$.

However, typical DEA models focus on the input and the final output, and do not consider the inner structure of the production activities. With respect to this, the network DEA proposed by Färe and Grosskopf (1996, 2000) evaluates the efficiency after modeling vertical or horizontal production activities.

The network DEA denotes the data value that corresponds to link $i (i = 1, ..., M)$ as z_i, the link data$_i$ that corresponds to DMU$_j$ $(j = 1, \cdots, n)$ as z_{ij}, and the evaluation value for link data item i as w_i. An absolute efficiency A for the DMN subject to evaluation is given by the following function when a link data $\mathbf{z} = (z_1, z_2, ..., z_M)^T$ and a link evaluation vector $\mathbf{w} = (w_1, w_2, ..., w_M)^T$ are given.

$$A = f(\mathbf{z}, \mathbf{w}) \tag{5}$$

This function form is called the "network efficiency function", and the point of network DEA is to define this function form. The absolute efficiency value A$_j$ for DMU$_j$ is given by formula (6).

$$A_j = f(\mathbf{z}_j, \mathbf{w}_j) \tag{6}$$

The relative efficiency value R$_j$(w) of DMU$_j$ for all DMU $(j = 1, \cdots, N)$ when an evaluation vector **w** is given is provided by Equation (7).

$$R_j(w) = \frac{A_j}{\max_j \{A_j\}} \tag{7}$$

The network DEA efficiency value for DMU$_j$ with an awareness of the internal network structure of DMU, is given by Equation (8).

$$E_j = \max_w \{R_j(\mathbf{w})\} \tag{8}$$

The structure of the Network DEA is shown in Fig. 2.

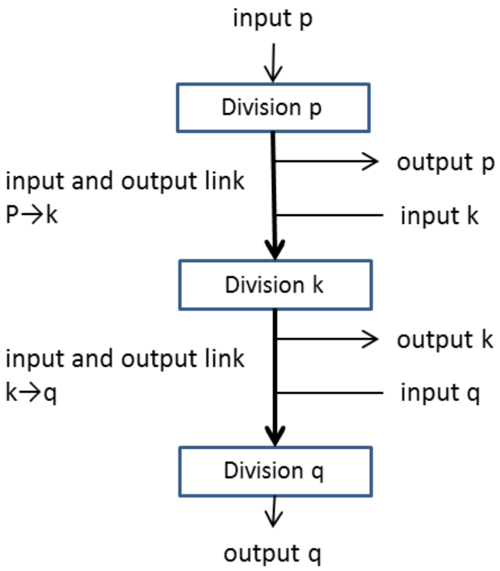

Figure 2, Structure of network DEA

3.3 Construction of an Efficiency Evaluation Method for Bus Routes

The operator of a bus company seeks to maximize revenue while minimizing expenses, and an increase in this management efficiency is the end goal. However, in a management efficiency resulting from personnel expenses, operation cost, and passenger fare revenue, the management conditions of individual bus routes cannot be analyzed in detail. Accordingly, it is necessary to evaluate more concrete efficiency values from various perspectives based on the characteristics of each route, such as service time, population along the route and length of route.

This research used a network DEA as shown in Fig. 2 to carry out analysis that subdivides the management efficiency of the bus company into “route arrangement efficiency” and "service efficiency.” That is, route arrangement efficiency evaluates the social importance of a route while effectively maintaining the population along the route and the number of passengers for a given route length or number of bus stops. Service efficiency evaluates how efficiently revenue is obtained for a given transportation cost, total service time or number of passengers.

Furthermore, social importance is evaluated on the basis of the number of accesses to commercial facilities (both large and small) and hospitals based on route buses supporting regional transportation.

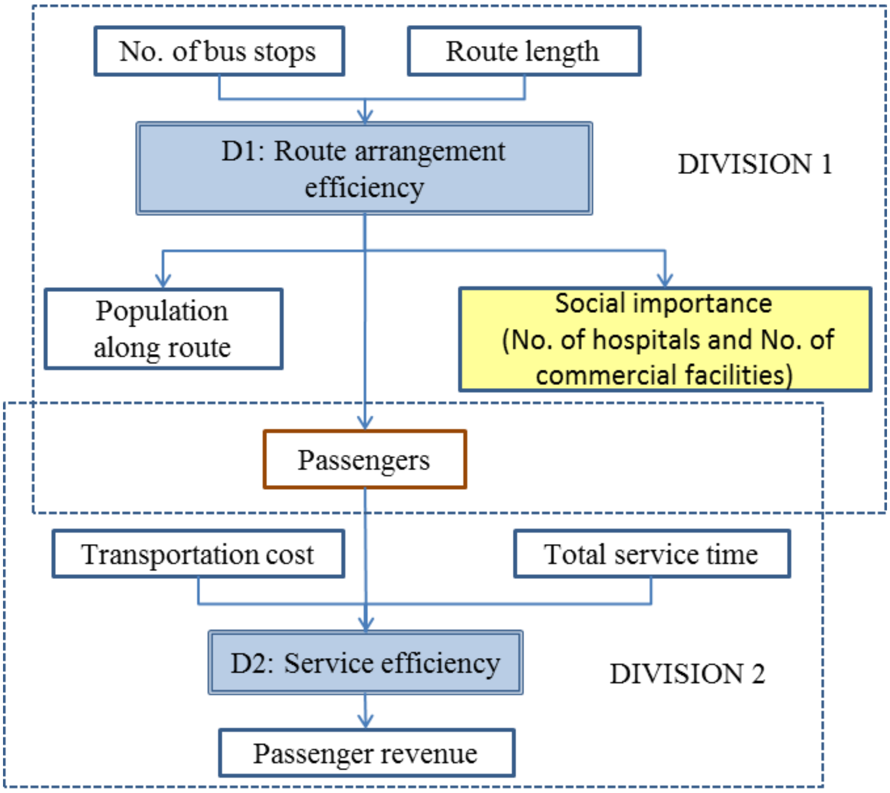

Figure 3. Analysis model for efficiency evaluation of bus routes

4. EFFICIENCY EVALUATION OF BUS ROUTES BY NETWORK DEA

4.1 Data

The parameters used for evaluating the efficiency of a bus route were route length (km), number of bus stops (points), population along the line (people) and social importance for the evaluation of Division 1 (route arrangement evaluation), and transportation cost (1000 yen), total service time (hours/day) and passenger revenue (1000 yen) for the evaluation of Division 2 (service efficiency). The data linking Division 1 and Division 2 were the number of passengers (people/year).

Also, regarding social importance, an area with a radius of 300 m from the target bus route was defined as the bus route's sphere of influence, and principal component analysis was applied to secondary and larger medical facilities, large-scale retail stores with a floor area of 1000 m^2 or more and small-scale retail stores (commodity supermarkets) located within the sphere of influence. The social importance of each bus route was calculated using the first principal component for which all symbols are nonnegative, as shown in Table 1. The analysis in this research used data for 2010, shown in Table 2.

Table 1. Results of principal component analysis

Variable	Principal Component 1	Principal Component 2	Principal Component 3
No. of Hospitals	0.881	0.204	-0.427
No. of Large Commercial Facilities	0.844	0.371	0.387
No. of Small Commercial Facilities	0.654	-0.753	0.075
Eigenvalue	1.917	0.745	0.338
Contribution Ratio	63.9%	24.8%	11.3%
Cumulative Contribution Ratio	63.9%	88.7%	100.0%

Table 2. Network DEA input/output data

Bus Route	Division1 Input		Division1 Output		Division2 Input		Division2 Output	Division1 & Division2 Link
	Route length (km)	No. of bus stops	Population along the route	Social importance	Transportation cost (1000 yen)	Total service time (hours/day)	Passenger revenue (1000 yen)	Number of passengers per year
Eifukukoutsuubu Line	29.9	41	28,326	141.8	123,723	62.6	124,132	610,231
Nisshinkoutsuubu Line	31.1	40	34,029	141.1	93,594	43.2	62,277	304,703
Tetsuhokukitaguchi Line	20.9	64	36,943	146.8	193,162	82.0	200,557	860,198
Greenbirudanchi Line	14.5	29	24,170	128.6	12,778	8.6	6,089	29,306
Sumikawanishikioka Lin	17.7	42	28,624	128.6	113,229	48.0	74,545	341,591
Kawazoitokiwa Line	17.6	37	25,229	106.4	79,693	31.2	49,837	219,428
Kinsaikouyou Line	17.4	41	27,946	150.3	68,393	30.0	52,177	233,559
Kinsaibunkakouen Line	25.1	48	29,789	140.0	13,261	8.0	7,590	32,367
Usunosawa Line	21.2	27	15,720	125.5	56,482	26.9	33,553	161,496
Miyanomori Line	14.8	27	21,814	116.0	52,964	23.0	30,417	142,617
Nishikioka Line	19.1	38	18,760	119.0	66,642	24.6	32,173	131,869
Keihokuyamate Line	14.1	24	17,012	122.5	14,191	7.6	6,577	33,510
Hamanasudanchi Line	16.4	26	17,536	125.6	8,689	5.2	3,333	13,486
Ekimaeshiritsubyouin Li	8.6	16	7,169	97.4	23,477	15.7	6,967	36,136
Hinodemachi Line	10.5	21	14,284	119.6	19,809	11.5	7,207	36,296
Minatomachi Line	11.9	20	9,908	112.3	18,775	10.6	7,798	42,286
Ferry Line	6.5	14	7,337	90.8	7,639	3.1	2,952	12,128
Yuufutsu Line	45.6	62	24,664	125.0	87,599	53.2	36,353	141,526
Numanohata Line	34.1	38	19,843	112.4	56,588	21.0	25,437	116,222
Tomatoukougyoukichi L	23.0	42	22,601	122.6	8,109	4.1	1,822	7,735
Uenae Line	44.7	42	18,245	106.5	21,454	7.6	6,807	30,479
Kinsaiuguisudanchi Line	10.7	13	1,896	78.8	939	0.6	89	725
Kinsaitarumaegaro Line	11.5	18	821	78.8	18,079	5.8	1,477	7,676

4.2 Analysis of Bus Route Efficiency

The results of the bus route efficiency evaluation by network DEA are shown in Table 3. The most efficient route in the overall evaluation was route No. 3, with route arrangement efficiency and service efficiency both evaluated as 1.0. This route was evaluated as having good service efficiency because it is the most profitable among all the Tomakomai bus routes. This route was also evaluated as having good route arrangement efficiency as it has many users, because it connects a residential area with a business district, it constitutes an important route that supports civic life and it provides access to hospitals and commercial facilities.

Bus routes 2 and 15 have few users and low service efficiency, despite having a comparatively large population along the route and high arrangement efficiency. There are many routes that compete with these two, and competition for bus users is an issue.

In this manner, it is possible to perform comprehensive evaluation by subdividing the evaluation of the bus route into route arrangement efficiency and service efficiency, and performing an organizational evaluation by network DEA based on the characteristics of a given bus route.

Table 3. Efficiency evaluation of bus routes

	Bus route	Overall evaluation	Route arrangement efficiency	Service efficiency
1	Eifukukoutsuubu Line	0.914	0.938	0.889
2	Nisshinkoutsuubu Line	0.846	1.000	0.692
3	Tetsuhokukitaguchi Line	1.000	1.000	1.000
4	Greenbirudanchi Line	0.704	1.000	0.408
5	Sumikawanishikioka Lir	0.799	0.964	0.635
6	Kawazoitokiwa Line	0.759	0.891	0.627
7	Kinsaikouyou Line	0.845	0.966	0.723
8	Kinsaibunkakouen Line	0.619	0.729	0.510
9	Usunosawa Line	0.647	0.754	0.541
10	Miyanomori Line	0.770	0.992	0.547
11	Nishikioka Line	0.590	0.680	0.500
12	Keihokuyamate Line	0.649	0.899	0.399
13	Hamanasudanchi Line	0.651	0.949	0.352
14	Ekimaeshiritsubyouin Li	0.572	0.910	0.234
15	Hinodemachi Line	0.674	1.000	0.348
16	Minatomachi Line	0.580	0.809	0.351
17	Ferry Line	0.867	1.000	0.734
18	Yuufutsu Line	0.382	0.424	0.340
19	Numanohata Line	0.495	0.526	0.464
20	Tomatoukougyoukichi L	0.598	0.999	0.198
21	Uenae Line	0.367	0.399	0.336
22	Kinsaiuguisudanchi Line	0.571	1.000	0.142
23	Kinsaitarumaegaro Line	0.367	0.583	0.151

The results of having analyzed the route arrangement efficiency and service efficiency by a scatter diagram are shown in Fig. 4. Routes with both high service efficiency and high route arrangement efficiency should continue operation in their current form. However, the service route or service time of routes that have low service efficiency despite having high route arrangement efficiency should be revised, as it is possible there are issues such as competition due to overlapping routes.

Routes that have both low route arrangement efficiency and low service efficiency, such as routes 21 and 18, are difficult to maintain, and the introduction of a new transportation system, such as shared taxis or demand-responsive transport (DRT) buses, should be considered as a replacement for these routes.

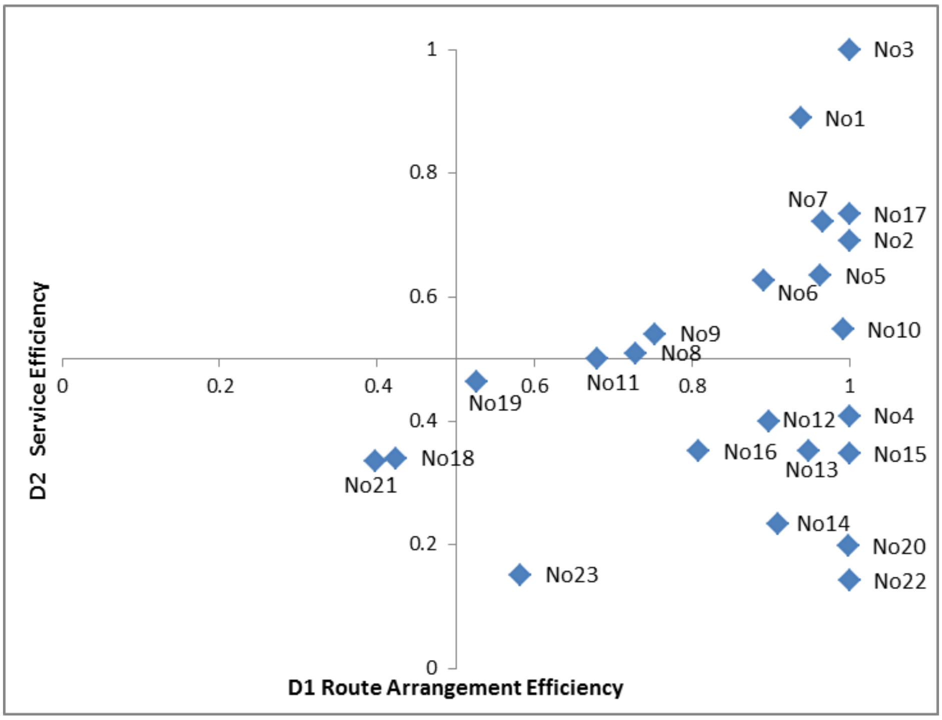

Figure 4. Relationship between service efficiency and route arrangement efficiency

5. CONCLUSION

With the remarkable decrease in the number of bus users due to depopulation, combined with the decreasing birthrate, the aging population and the establishment of automobile-dependent lifestyles, the maintenance of bus transportation is becoming a serious issue for many municipalities. So far, self-supported endeavors have been proactively implemented, such as measures for reducing expenses by reducing personnel, abolishing routes and curtailing the number of services per day. However, as a result, in some cases this has led to a decline in bus service standards, further driving away bus users.

Also, since buses are an important means of transport supporting the lives of mobility-impaired people, municipalities can find themselves obliged to maintain routes even if they run at a loss. Such routes continue to be supported by large subsidies, but the serious deterioration of local government finances means that there is a limit to this approach.

This research used network DEA to focus on the route arrangement efficiency and service efficiency of bus routes and reach a stage-by-stage understanding of the revenue and expenditure management of bus routes, providing a structured view of the stages causing problems. As a result, routes that have low service efficiency despite having high route arrangement efficiency were determined, and it became clear that factors such as competition between bus routes are becoming an issue. Also, since an improvement in service cannot be expected for routes of both low route arrangement efficiency and low service efficiency, it may be necessary to consider alternative transportation systems.

In this study, it was possible to evaluate bus routes from multiple perspectives in addition to revenue and expenses, through structural evaluation of bus routes by network DEA. In future work, we plan to evaluate bus routes in large cities as well as suburban towns.

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