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Soushi Suzuki[1]
Peter Nijkamp[2]

[1] *Hokkai-Gakuen University, Sapporo, Japan;*
[2] *VU University Amsterdam, and Tinbergen Institute.*

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The Netherlands
Tel.: +31(0)20 525 8579

A Stepwise Projection Data Envelopment Analysis for Public Transport Operations in Japan

Soushi Suzuki[a] Peter Nijkamp[b]

[a]Hokkai-Gakuen University, Department of Civil and Environmental Engineering, South26-West 11,1-1,chuo-ku, 064-0926 Sapporo, Japan

[b]VU University Amsterdam, Department of Spatial Economics, De Boelelaan 1105, 1081 HV Amsterdam, The Netherlands

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Abstract

With tightening budgets and increasingly critical reviews of public expenditure, there is a need for a careful analysis of the performance of public bodies in terms of an efficient execution of their tasks. These questions show up everywhere in the public domain, for instance, in the provision of medical facilities, the operation of postal services, or the supply of public transport. A standard tool to judge the efficiency of such agencies is Data Envelopment Analysis (DEA). In the past years, much progress has been made to extend this approach in various directions. Examples are the Distance Friction Minimization (DFM) model and the Context-Dependent (CD) model.

The DFM model is based on a generalized distance friction function and serves to improve the performance of a Decision Making Unit (DMU) by identifying the most appropriate movement towards the efficiency frontier surface. Standard DEA models use a uniform proportional input reduction (or a uniform proportional output increase) in the improvement projections, but the DFM approach aims to enhance efficiency strategies by introducing a weighted projection function. This approach may address both input reduction and output increase as a strategy of a DMU. A suitable form of multidimensional projection functions is given by a Multiple Objective Quadratic Programming (MOQP) model using a Euclidean distance. Likewise, the CD model yields efficient frontiers in different levels, while it is based on a level-by-level improvement projection.

The present paper will first offer a new integrated DEA tool – emerging from a blend of the DFM and CD model using the Charnes-Cooper-Rhodes (CCR) method – in order to design a stepwise efficiency-improving projection model for a conventional DEA. The above-mentioned stepwise-projection model is illustrated on the basis of an application to the efficiency analysis of public transport operations in Japan.

Keywords: Data Envelopment Analysis (DEA), Stepwise projection, Distance Friction Minimization, Context-dependence, public transport operations

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*Corresponding author: Soushi Suzuki (e-mail address: soushi-s@cvl.hokkai-s-u.ac.jp)

1. Introduction

With tightening budgets and increasingly critical reviews of public expenditure, there is a need for a careful analysis of the performance of public bodies in terms of an efficient execution of their tasks. These questions show up everywhere in the public domain, for instance, in the provision of medical facilities, the operation of postal services, or the supply of public transport.

A standard tool to judge the efficiency of such agencies is Data Envelopment Analysis (DEA). DEA has gained much importance in economic performance studies. Seiford (2005) mentions some 2800 published articles on DEA. This large number of studies shows that comparative efficiency analysis has become an important topic in both the private and public sector. DEA was developed to analyze the relative efficiency of agents or decision makers, in general, Decision Making Unit (DMU), by constructing a piecewise linear production frontier, and projecting the performance of each DMU onto the frontier. A DMU that is located on the frontier is efficient, while a DMU that is not on the frontier is inefficient. An inefficient DMU can become efficient by reducing its inputs or increasing its outputs. In the standard DEA approach, this is achieved by a uniform reduction in all inputs (or a uniform increase in all outputs). But in principle, there are an infinite number of improvements to reach the efficient frontier, and hence there are many solutions for a DMU to enhance efficiency. The existence of an infinite number of solutions to reach the efficient frontier has led to a stream of literature on the integration of DEA and Multiple Objective Linear Programming (MOLP), which was initiated by Golany (1988).

Suzuki and Nijkamp (2007a, 2010a, and 2010b) proposed a Distance Friction Minimization (DFM) model that is based on a generalized distance friction function and serves to improve the performance of a DMU by identifying the most appropriate movement towards the efficiency frontier surface. This approach may address both an input reduction and an output increase as a strategy of a DMU. A suitable form of multidimensional projection functions is given by a Multiple Objective Quadratic Programming (MOQP) model using a Euclidean distance. A general efficiency-improving projection model including a DFM model is able to calculate either an optimal input reduction value or an output increase value to reach an efficient score of 1.0, even though in reality this may be hard to achieve.

It is noteworthy that Seiford and Zhu (2003) developed a gradual improvement model for an inefficient DMU. This 'Context-Dependent (CD)' DEA has an important merit, as it aims to reach a stepwise improvement through successive levels towards the efficiency frontier. The CD model will be used as an ingredient in the DFM model.

This paper will first design a new integrated DEA tool emerging from a blend of the DFM and CD model, namely a Stepwise DFM model, in order to design a stepwise efficiency-improving projection model for a conventional DEA. The above-mentioned stepwise-projection model is illustrated on the basis of an application to the efficiency analysis of public transport operations in Japan.

2. Efficiency Improvement Projection in DEA: the Standard Approach

The standard Charnes et al. (1978) model (abbreviated hereafter as the CCR-input model) for a given DMU$_j$ $(j = 1, \cdots, J)$ to be evaluated in any trial o (where o ranges over 1, 2 …, J) may be represented as the following fractional programming (FP_o) problem:

$$(FP_o) \qquad \max_{v,u} \quad \theta = \frac{\sum_s u_s y_{so}}{\sum_m v_m x_{mo}}$$

$$\text{s.t.} \quad \frac{\sum_s u_s y_{sj}}{\sum_m v_m x_{mj}} \leq 1 \quad (j = 1, \cdots, J) \tag{2.1}$$

$$v_m \geq 0, \; u_s \geq 0,$$

where θ represents an objective variable function (efficiency score); x_{mj} is the volume of input m (m=1,…, M) for DMU j (j=1,…,J); y_{sj} is the output s (s=1,…,S) of DMU j; and v_m and u_s are the weights given to input m and output s, respectively. Model (2.1) is often called an input-oriented CCR model, while its reciprocal (i.e. an interchange of the numerator and denominator in objective function (2.1), with a specification as a minimization problem under an appropriate adjustment of the constraints) is usually known as an output-oriented CCR model. Model (2.1) is obviously a fractional programming model, which may be solved stepwise by first assigning an arbitrary value to the denominator in (2.1), and then maximizing the numerator.

The improvement projection $(\hat{x}_o, \hat{y}_o)$ can now be defined in (2.2) and (2.3) as:

$$\hat{x}_o = \theta^* x_o - s^{-*}; \tag{2.2}$$

$$\hat{y}_o = y_o + s^{+*}. \tag{2.3}$$

These equations indicate that the efficiency of (x_o, y_o) for DMU$_o$ can be improved if the input values are reduced radially by the ratio θ^*, and the input excesses s^{-*} are eliminated (see Figure 1). The original DEA models presented in the literature have thus far only focused on a uniform input reduction or a uniform output increase in the efficiency-improvement projections, as shown in Figure 1 (θ^*=OC'/OC).

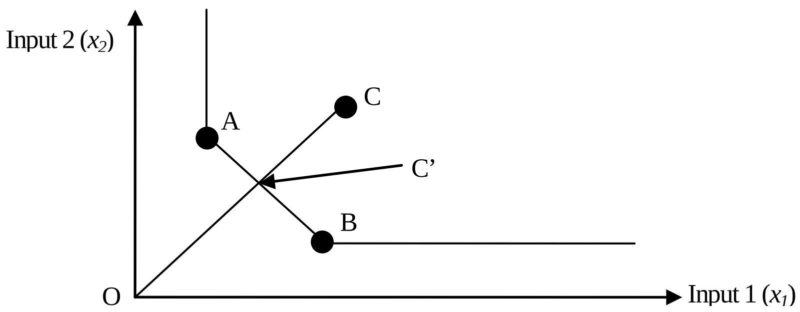

Figure 1 Illustration of original DEA projection in input space

3. The Distance Friction Minimization (DFM) Approach

As mentioned, the efficiency improvement solution in the original CCR-input model requires that the input values are reduced radially by a uniform ratio θ^* (θ^*=OD'/OD in Figure 2).

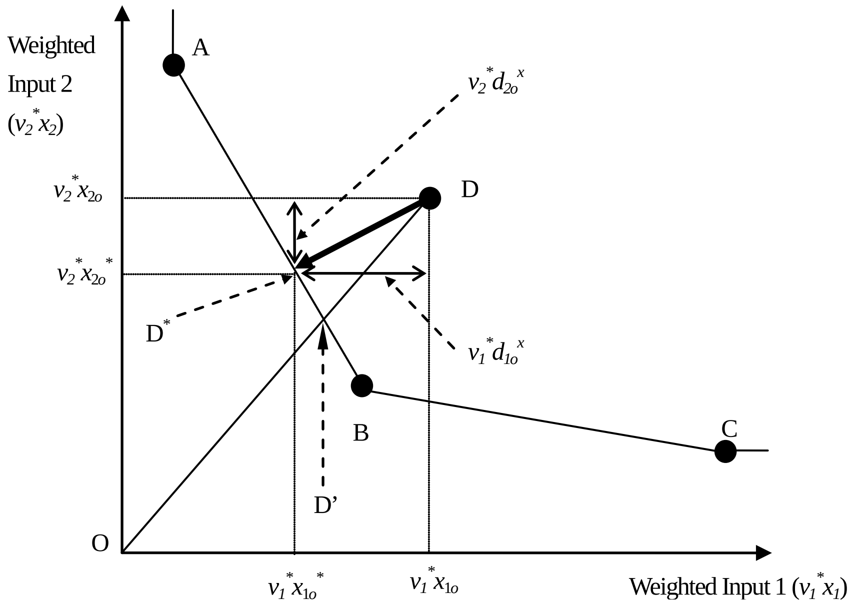

Figure 2 Illustration of the DFM approach (Input- $v_i^* x_i$ space)

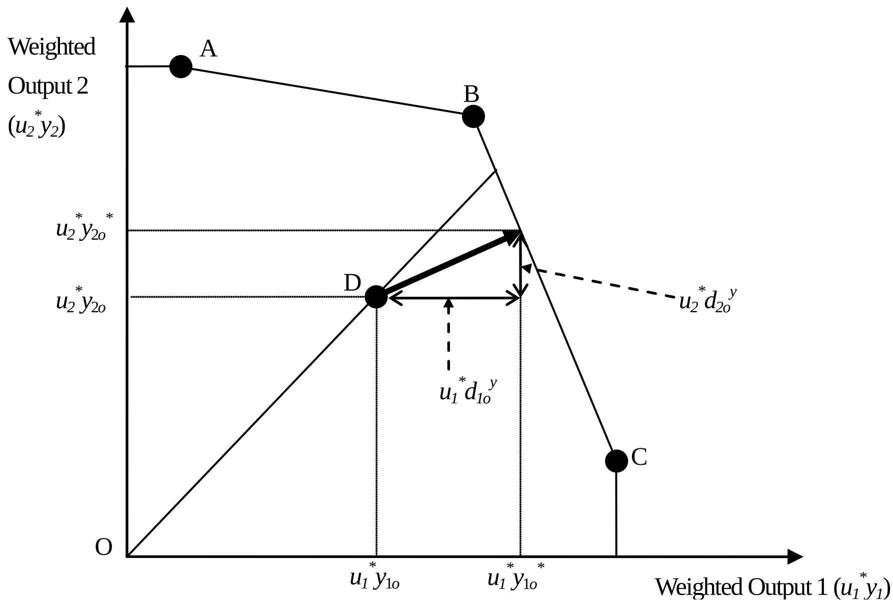

Figure 3 Illustration of the DFM approach (Output - $u_r^* y_r$ space)

The (v^*, u^*) values obtained as an optimal solution for formula (2.1) result in a set of optimal weights for DMU_o. As mentioned earlier, (v^*, u^*) is the set of most favourable weights for DMU_o, in the sense of maximizing the ratio scale. v_m^* is the optimal weight for the input item *m*, and its magnitude expresses how much in relative terms the item is contributing to efficiency. Similarly, u_s^* does the same for the output item *s*. These values show not only which items contribute to the performance of DMU_o, but also to what extent they do so. In other words, it is possible to express the distance frictions (or alternatively, the potential increases) in improvement projections.

In this study, we use the optimal weights u_s^* and v_m^* from (2.1), and then describe next efficiency improvement projection model. A visual presentation of this new approach is given in Figures 2 and 3.

In this approach a generalized distance friction is deployed to assist a DMU in improving its efficiency by a movement towards the efficiency frontier surface. The direction of efficiency improvement depends of course on the input/output data characteristics of the DMU. It is now appropriate to define the projection functions for the minimization of distance friction by using a Euclidean distance in weighted spaces. As mentioned, a suitable form of multidimensional projection functions that serves to improve efficiency is given by a MOQP model which aims to minimize the aggregated input reduction frictions, as well as the aggregated output increase frictions. Thus, the DFM approach can generate a new contribution to efficiency enhancement problems in decision analysis, by deploying a weighted Euclidean projection function, and at the same time it may address both input reduction and output increase. The details of this approach have been outlined elsewhere (see Suzuki et al. 1997a, b, c). Here we will only describe the various steps concisely.

First, specify the distance friction function Fr^x and Fr^y by means of (3.1) and (3.2), which are defined by the Euclidean distance shown in Figures 2 and 3. Next, solve the following MOQP by using d^x_{mo} (a reduction of distance for x_{io}) and d^y_{so} (an increase of distance for y_{so}) as minimands in an L_2 metric:

$$\min \ Fr^x = \sqrt{\sum_m \left(v^*_m x_{mo} - v^*_m d^x_{mo}\right)^2} \tag{3.1}$$

$$\min \ Fr^y = \sqrt{\sum_s \left(u^*_s y_{so} - u^*_s d^y_{so}\right)^2} \tag{3.2}$$

$$\text{s.t.} \quad \sum_m v^*_m \left(x_{mo} - d^x_{mo}\right) = \frac{2\theta^*}{1+\theta^*} \tag{3.3}$$

$$\sum_s u^*_s \left(y_{so} + d^y_{so}\right) = \frac{2\theta^*}{1+\theta^*} \tag{3.4}$$

$$x_{mo} - d^x_{mo} \geq 0 \tag{3.5}$$

$$d^x_{mo} \geq 0 \tag{3.6}$$

$$d^y_{so} \geq 0 , \tag{3.7}$$

where x_{mo} is the amount of input item *m* for any arbitrary inefficient DMU_o, and y_{so} is the amount of output item *s* for any arbitrary inefficient DMU_o. Constraint functions (3.3) and (3.4) refer to the target values of input reduction and output increase. It is now possible to determine each optimal distance d^{x*}_{mo} and d^{y*}_{so} by using the MOQP model (3.1)-(3.7).

The friction minimization solution for an inefficient DMU_o can now be expressed by means of formulas (3.8) and (3.9):

$$x^*_{mo} = x_{mo} - d^{x*}_{mo} \tag{3.8}$$

$$y^*_{so} = y_{so} + d^{y*}_{so} \quad . \tag{3.9}$$

By means of the DFM model, it is possible to present a new efficiency-improvement solution based on the standard CCR projection. This means an increase in new options for efficiency-improvement solutions in DEA. The main advantage of the DFM model is that it yields an outcome on the efficient frontier that is as close as possible to the DMU's input and output profile (see Figure 4).

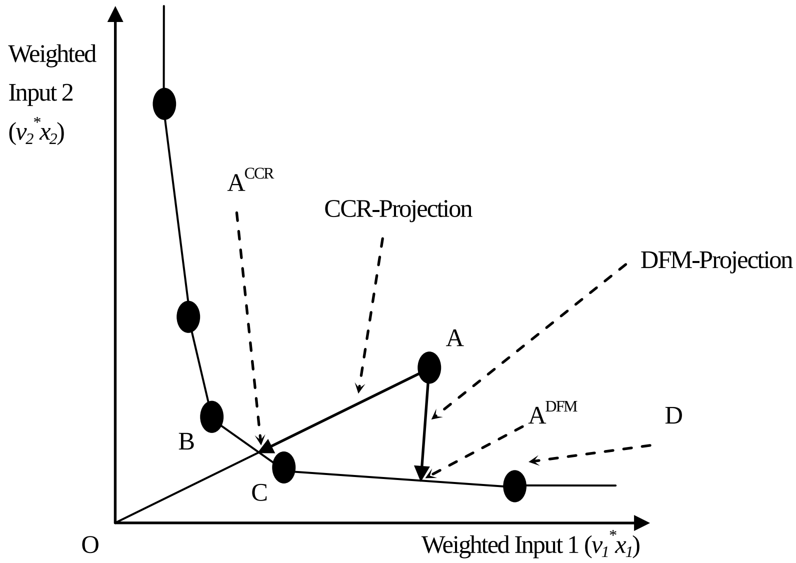

Figure 4 Degree of improvement of a DFM-projection and a CCR-projection in weighted input space

4. Context-Dependent DEA

The Context-Dependent (CD hereafter) model can obtain efficient frontiers in different levels, and can yield a level-by-level improvement projection. The CD model is formulated below.

Let $J^l = \{DMU_j, j = 1, \cdots, J\}$ be the set of all J DMUs. We interactively define $J^{l+1} = J^l - E^l$ where $E^l = \{DMU_k \in J^l | \theta^*(l,k)\} = 1$ and $\theta^*(l,k)$ is the optimal value by using formula (2.2).

When $l = 1$, it becomes the original CCR model and the DMUs in set E_l define the first-level efficient frontier. When $l = 2$, it gives the second-level efficient frontier after the exclusion of the first-level efficient DMUs. And so on. In this manner, we identify several levels of efficient frontiers. We call E_l the lth-level efficient frontier. The following algorithm accomplishes the identification of these efficient frontiers.

Step 1: Set l = 1. Evaluate the entire set of DMUs, J_1,. We obtain then the first-level efficient DMUs for set E_1 (the first-level efficient frontier).

Step 2: Exclude the efficient DMUs from future DEA runs. $J^{l+1} = J^l - E^l$ (If $J^{l+1} = \phi$, then stop.)

Step 3: Evaluate the new subset of "inefficient" DMUs. We obtain then a new set of efficient DMUs E^{l+1} (the new efficient frontier).

Step 4: Let $l = l + 1$. Go to step 2.

Stopping rule: $J^{l+1} = \phi$, the algorithm is terminated.

A visual presentation of the CD model is given in Figure 5.

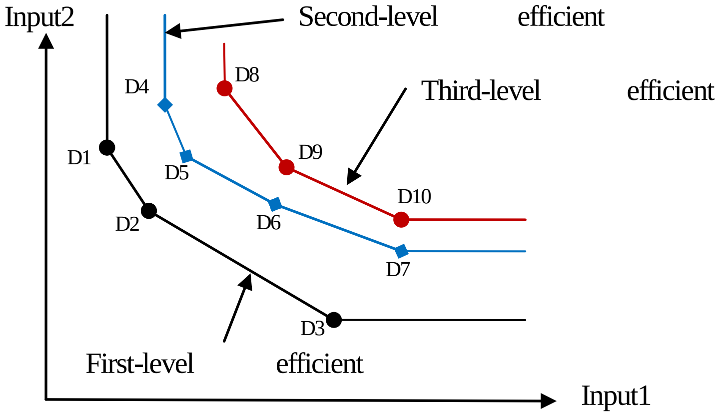

Figure 5 Illustration of the CD model

5. Stepwise-DFM Model in DEA

This section is devoted to an integration of CD and DFM models. We propose a Stepwise DFM model that is integrated with a DFM and CD model.

Any efficiency-improving projection model which includes the standard CCR projection supplemented with the DFM-projection is always directed towards achieving "full efficiency". This strict condition may not always be easy to achieve in reality. Therefore, in this section we will develop a new efficiency improving projection model, which aims to integrate with CD model and DFM approach, the "Stepwise Distance Friction Minimization" (Stepwise DFM hereafter) model. It can yield a stepwise efficiency improving projection that depends on l -level efficient frontiers (l-level DFM projection), as shown in Figure 6.

For example, a second-level DFM projection for DMU10 (D10) aims to position DMU10 on a second-level efficient frontier. And a first-level DFM projection is just equal to a DFM projection (3.1)-(3.7). We notice here that the second-level DFM projection is easier to achieve than a first-level DFM projection. A stepwise-DFM model can yield a more practical and realistic efficiency improving projection than a CCR Projection or a DFM Projection.

The advantage of the Stepwise DFM model is also that it yields an outcome on a l-level efficient frontier that is as close as possible to the DMU's input and output profile (see Figure 6).

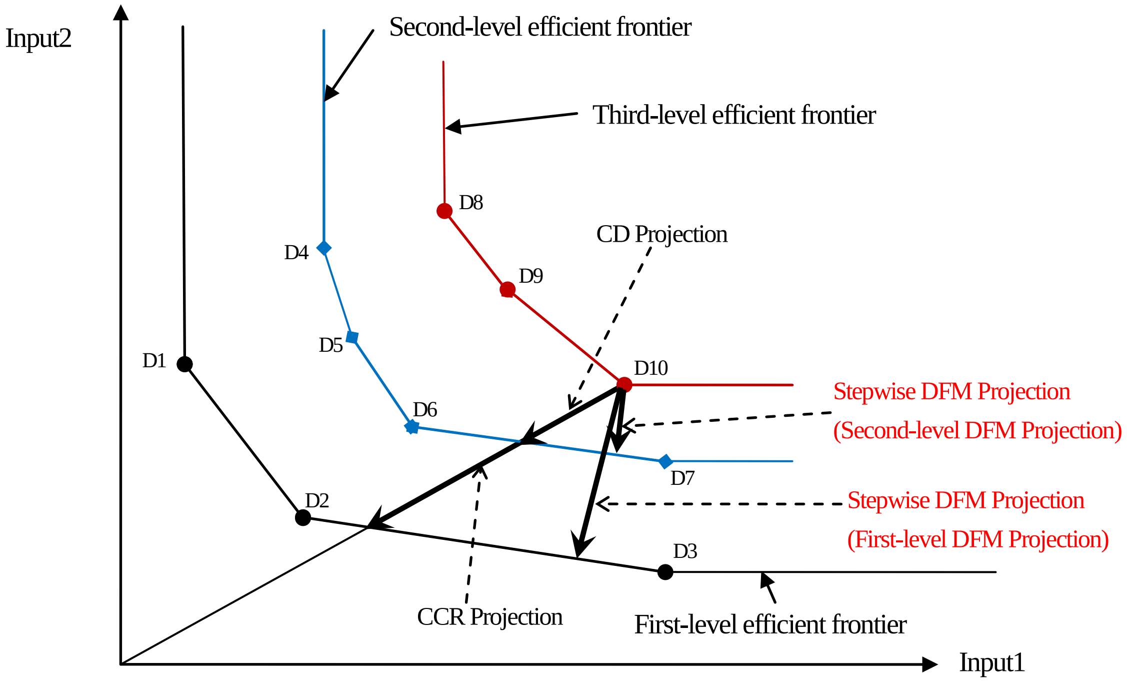

Figure 6 Illustration of the CD model

6. Application of a Stepwise DFM Model to Public Transport Efficiency Management

6.1 Database and analysis framework

In our empirical work, we use input and output data for a set of 9 urban transportation authorities and 16 major private railway companies in Japan. The DMUs used in our analysis are listed in Table 1.

Table 1 A listing of DMUs

No	*major private railway companies*	No	*urban transportation authorities*
1	Tobu	1	Sapporo
2	Seibu	2	Sendai
3	Keisei	3	Tokyo
4	Keio	4	Yokohama
5	Odakyu	5	Nagoya
6	Tokyu	6	Kyoto
7	Keikyu	7	Osaka
8	Sotetsu	8	Kobe
9	Meitetsu	9	Fukuoka
10	Kintetsu		
11	Nankai		
12	Keihan		
13	Hankyu		
14	Hanshin		
15	Nishitetsu		
16	Tokyometro		

In this study we use the following inputs and outputs:

- Input:

(I) Operating cost (in 2007);

(I) Railway business property (in 2007);

- Output:

(O) Operating revenues (in 2007);

All data were obtained from the "Railway annual statement 2007". In our application, we first applied the standard CCR model, while next the results were used to determine the CCR and DFM projections. Additionally, we applied the CD model, and then the results were used to determine the CD and Stepwise DFM projections. Finally, these various results were mutually compared. The steps followed in our analysis are presented in Figure 7.

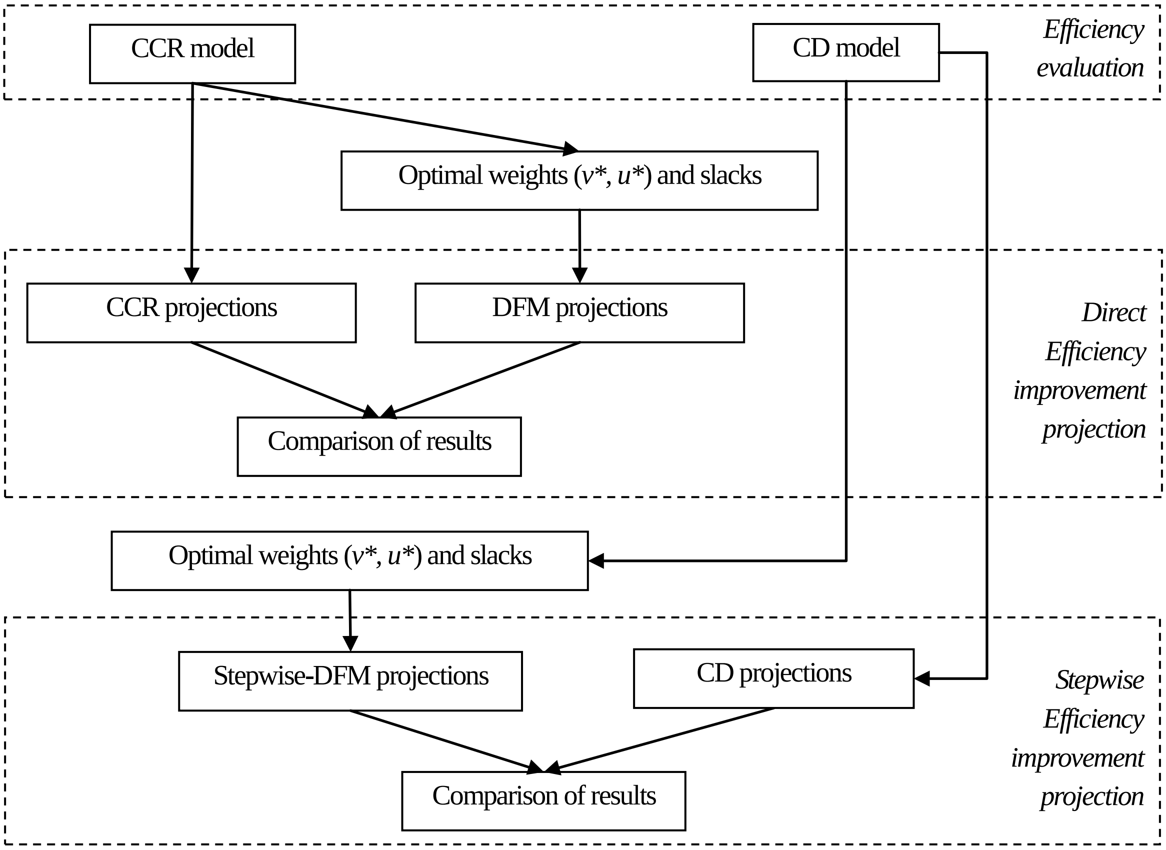

Figure 7 Analysis framework of the Stepwise DFM model

6.2 Efficiency evaluation based on the CCR model

The efficiency evaluation results for the 25 public transport corporations based on the CCR model is given in Figure 8. From Figure 8, it can be seen that Keio and Tokyometro are efficiently-operating corporations. On the other hand, Kyoto has a low efficiency (i.e., an efficiency score around 50 per cent). Furthermore, Kobe and Fukuoka also has a low efficiency.

It is noteworthy that the average efficiency level of urban transportation authorities is relatively low compared to major private railway companies. It is considered that apparently transportation authorities have still much room for further efficiently-enhancing strategies.

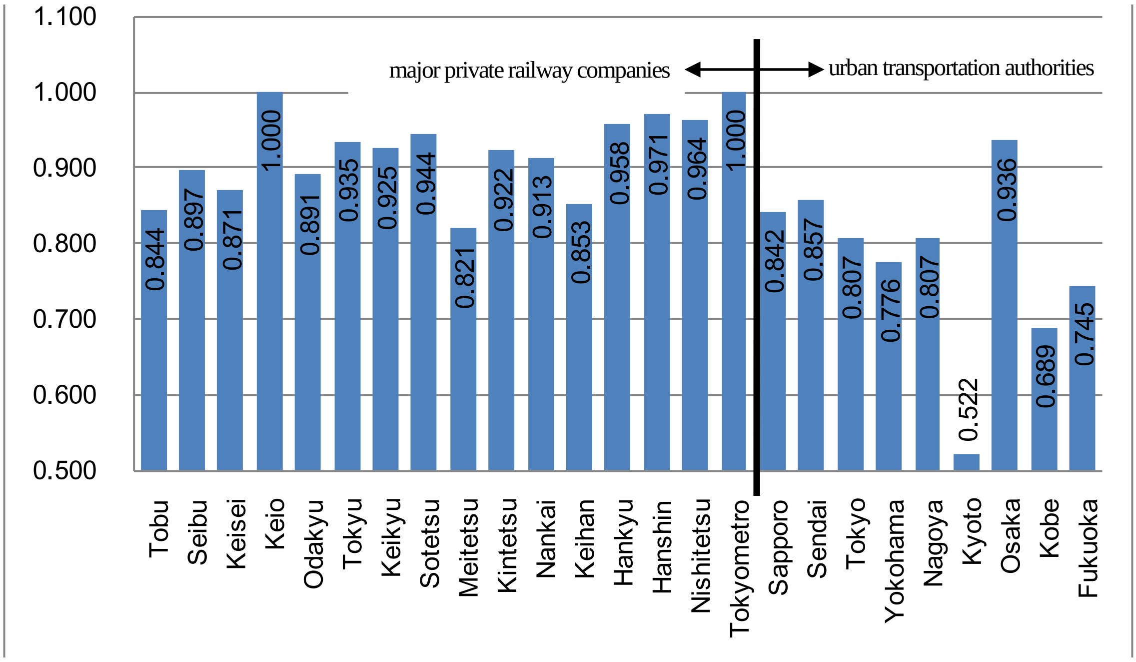

Figure 8 Efficiency score based on the CCR model

6.3 Direct efficiency improvement projection based on the CCR and DFM models

The direct efficiency improvement projection results based on the CCR and DFM model for inefficient public transport corporations are presented in Table 2.

In Table 2, it appears that the empirical ratios of change in the DFM projection are smaller than those in the CCR projection, as was expected. In Table 2, this particularly applies to Seibu, Tokyu, Keikyu, Hanshin and Nishitetsu, which are apparently non-slack type (i.e. s^{-**} and s^{+**} are zero) corporations. The DFM projection involves both input reduction and output increase, and, clearly, the DFM projection does not involve a uniform ratio, because this model looks for the optimal input reduction (i.e., the shortest distance to the frontier, or distance friction minimization). For instance, the CCR projection shows that Seibu should reduce the Operating cost and the Railway business property by 10.34 per cent in order to become efficient. On the other hand, the DFM results show that a reduction in Railway business property of 9.96 per cent and an increase in the Operating revenues of 5.45 per cent are required to become efficient. Apart from the practicality of such a solution, the models show clearly that a different – and perhaps more efficient – solution is available than the standard CCR projection to reach the efficiency frontier.

Table 2 Direct efficiency-improvement projection results of the CCR and DFM model

		CCC Projection		DFM Projection	
DMU	Score(θ*)	Score(θ**)		Score(θ**)	
I/O	Data	Difference	%	Difference $d_{mo}^{x*}+s^{-**}$ $d_{so}^{y*}+s^{+**}$	%
Tobu	0.844	1.000		1.000	
(I)cost	137242584	-21367976	-15.57%	-11585923	-8.44%
(I)property	712422107	-236943047	-33.26%	-196803438	-27.62%
(O)revenue	160818200	0	0.00%	13576160	8.44%
Seibu	0.897	1.000		1.000	
(I)cost	84550368	-8743438	-10.34%	0	0.00%
(I)property	329209999	-34043933	-10.34%	-32801294	-9.96%
(O)revenue	102197169	0	0.00%	5572273	5.45%
Keisei	0.871	1.000		1.000	
(I)cost	45143268	-5805106	-12.86%	-3102001	-6.87%
(I)property	203714344	-42294404	-20.76%	-31202500	-15.32%
(O)revenue	54596020	0	0.00%	3751543	6.87%
Odakyu	0.891	1.000		1.000	
(I)cost	95105070	-10371194	-10.90%	-5484647	-5.77%
(I)property	503547659	-155851263	-30.95%	-135799840	-26.97%
(O)revenue	117599098	0	0.00%	6781863	5.77%
Tokyu	0.935	1.000		1.000	
(I)cost	116330884	-7529603	-6.47%	0	0.00%
(I)property	448779376	-29047580	-6.47%	-27543332	-6.14%
(O)revenue	145938161	0	0.00%	4880939	3.34%
Keikyu	0.925	1.000		1.000	
(I)cost	64879034	-4856935	-7.49%	0	0.00%
(I)property	240695337	-18018789	-7.49%	-17487164	-7.27%
(O)revenue	78827586	0	0.00%	3065308	3.89%
Sotetsu	0.944	1.000		1.000	
(I)cost	26015702	-1446977	-5.56%	-744184	-2.86%
(I)property	111527822	-10712689	-9.61%	-7828852	-7.02%
(O)revenue	34098049	0	0.00%	975381	2.86%
Meitetsu	0.821	1.000		1.000	
(I)cost	76843610	-13765418	-17.91%	-7559826	-9.84%
(I)property	409977161	-151142549	-36.87%	-125678563	-30.66%
(O)revenue	87543953	0	0.00%	8612519	9.84%
Kintetsu	0.922	1.000		1.000	
(I)cost	131011669	-10160605	-7.76%	-5285251	-4.03%
(I)property	771942168	-276042754	-35.76%	-256037261	-33.17%
(O)revenue	167724844	0	0.00%	6766328	4.03%
Nankai	0.913	1.000		1.000	
(I)cost	46384894	-4028874	-8.69%	-2105893	-4.54%
(I)property	294000567	-120197168	-40.88%	-112306423	-38.20%
(O)revenue	58784397	0	0.00%	2668836	4.54%
Keihan	0.853	1.000		1.000	
(I)cost	46034077	-6752320	-14.67%	-3643366	-7.91%
(I)property	199915154	-38726667	-19.37%	-25969407	-12.99%
(O)revenue	54517737	0	0.00%	4314805	7.91%
Hankyu	0.958	1.000		1.000	
(I)cost	75171681	-3166136	-4.21%	-1617123	-2.15%
(I)property	399741850	-104274797	-26.09%	-97918591	-24.50%
(O)revenue	99933906	0	0.00%	2149818	2.15%

		CCC Projection		DFM Projection	
DMU	Score(θ*)	Score(θ**)		Score(θ**)	
I/O	Data	Difference	%	Difference $d_{mo}^{x*}+s^{-**}$ $d_{so}^{y*}+s^{+**}$	%
Hanshin	0.971	1.000		1.000	
(I)cost	20880360	-614986	-2.95%	0	0.00%
(I)property	71623305	-2109509	-2.95%	-2075902	-2.90%
(O)revenue	25540600	0	0.00%	381743	1.49%
Nishitetsu	0.964	1.000		1.000	
(I)cost	18416583	-662304	-3.60%	0	0.00%
(I)property	66379457	-2387163	-3.60%	-2301763	-3.47%
(O)revenue	22961699	0	0.00%	420439	1.83%
Sapporo	0.842	1.000		1.000	
(I)cost	31887493	-5052884	-15.85%	-2743836	-8.60%
(I)property	406895116	-296782167	-72.94%	-287307235	-70.61%
(O)revenue	37242789	0	0.00%	3204645	8.60%
Sendai	0.857	1.000		1.000	
(I)cost	9547699	-1364705	-14.29%	-734872	-7.70%
(I)property	123357198	-89779157	-72.78%	-87194706	-70.68%
(O)revenue	11356883	0	0.00%	874122	7.70%
Tokyo	0.807	1.000		1.000	
(I)cost	112204498	-21667753	-19.31%	-11991735	-10.69%
(I)property	1692909251	-1321401400	-78.06%	-1281696898	-75.71%
(O)revenue	125652692	0	0.00%	13428996	10.69%
Yokohama	0.776	1.000		1.000	
(I)cost	28808045	-6447669	-22.38%	-3630066	-12.60%
(I)property	735299032	-643545619	-87.52%	-631983887	-85.95%
(O)revenue	31033162	0	0.00%	3910450	12.60%
Nagoya	0.807	1.000		1.000	
(I)cost	61326002	-11809506	-19.26%	-6533864	-10.65%
(I)property	780732042	-577546396	-73.97%	-555898363	-71.20%
(O)revenue	68722164	0	0.00%	7321874	10.65%
Kyoto	0.522	1.000		1.000	
(I)cost	29271536	-13998476	-47.82%	-9198802	-31.43%
(I)property	494381778	-431710412	-87.32%	-412015460	-83.34%
(O)revenue	21196930	0	0.00%	6661296	31.43%
Osaka	0.936	1.000		1.000	
(I)cost	117496019	-7557800	-6.43%	-3904476	-3.32%
(I)property	1248374651	-797254929	-63.86%	-782263903	-62.66%
(O)revenue	152579299	0	0.00%	5070318	3.32%
Kobe	0.689	1.000		1.000	
(I)cost	18685348	-5803544	-31.06%	-3435255	-18.38%
(I)property	309292607	-256433500	-82.91%	-246715483	-79.77%
(O)revenue	17878193	0	0.00%	3286862	18.38%
Fukuoka	0.745	1.000		1.000	
(I)cost	22083430	-5629935	-25.49%	-3226212	-14.61%
(I)property	491943185	-424428028	-86.28%	-414564606	-84.27%
(O)revenue	22835214	0	0.00%	3336041	14.61%

6.4 Stepwise efficiency improvement projection based on the CD and Stepwise DFM models

The efficiency improvement projection results for the nearest upper level efficient frontier based on the CD and Stepwise-DFM model for inefficient public transport corporation are presented in Table 3.

In Table 3, it appears that the ratios of change in the Stepwise DFM projection are smaller than those in the CD projection, as was expected. In Table 3, this particularly applies to Tobu, Seibu, Keisei, Odakyu, Tokyu, Keikyu, Meitetsu, Nankai, Heihan, Hanshin, Nishitetsu, Sapporo, Nagoya, and Kyoto, which are non-slack type (i.e. s^{-**} and s^{+**} are zero) corporations. Apart from the practicality of such a solution, the models show clearly that a different – and perhaps more efficient – solution is available than the CD projection to reach the efficiency frontier.

Table 3 Efficiency-improvement projection results for nearest upper level efficient frontier

	DMU	Score(θ*)	CD Projection		Stepwise-DFM Projection	
	I/O	Data	Difference	%	Difference $d_{mn}^{x*}+s^{-**}$ $d_{so}^{y*}+s^{+**}$	%
E2	Sotetsu	0.944				
	(I)cost	26015702	-1446977	-5.56%	-744184	-2.86%
	(I)property	111527822	-10712689	-9.61%	-7828852	-7.02%
	(O)revenue	34098049	0	0.00%	975381	2.86%
	Hankyu	0.958				
	(I)cost	75171681	-3166136	-4.21%	-1617123	-2.15%
	(I)property	399741850	-104274797	-26.09%	-97918591	-24.50%
	(O)revenue	99933906	0	0.00%	2149818	2.15%
	Hanshin	0.971				
	(I)cost	20880360	-614986	-2.95%	0	0.00%
	(I)property	71623305	-2109509	-2.95%	-2075902	-2.90%
	(O)revenue	25540600	0	0.00%	381743	1.49%
	Nishitetsu	0.964				
	(I)cost	18416583	-662304	-3.60%	0	0.00%
	(I)property	66379457	-2387163	-3.60%	-2301763	-3.47%
	(O)revenue	22961699	0	0.00%	420439	1.83%
E3	Tokyu	0.987				
	(I)cost	116330884	-1465276	-1.26%	-1029922	-0.89%
	(I)property	448779376	-5652717	-1.26%	0	0.00%
	(O)revenue	145938161	0	0.00%	924926	0.63%
	Keikyu	0.967				
	(I)cost	64879034	-2151905	-3.32%	-1511718	-2.33%
	(I)property	240695337	-7983371	-3.32%	0	0.00%
	(O)revenue	78827586	0	0.00%	1329320	1.69%
	Kintetsu	0.963				
	(I)cost	131011669	-4846697	-3.70%	-2469018	-1.88%
	(I)property	771942168	-101032343	-13.09%	-88388517	-11.45%
	(O)revenue	167724844	0	0.00%	3160907	1.88%
	Osaka	0.977				
	(I)cost	117496019	-2723737	-2.32%	-1377839	-1.17%
	(I)property	1248374651	-638047949	-51.11%	-630890840	-50.54%
	(O)revenue	152579299	0	0.00%	1789250	1.17%
E4	Seibu	0.963				
	(I)cost	84550368	-3115939	-3.69%	-1652015	-1.95%
	(I)property	329209999	-12132392	-3.69%	0	0.00%
	(O)revenue	102197169	0	0.00%	1918490	1.88%
	Nankai	0.989				
	(I)cost	46384894	-529772	-1.14%	-271618	-0.59%
	(I)property	294000567	-3357848	-1.14%	0	0.00%
	(O)revenue	58784397	0	0.00%	337623	0.57%
E5	Keisei	0.988				
	(I)cost	45143268	-522332	-1.16%	-288164	-0.64%
	(I)property	203714344	-2357087	-1.16%	0	0.00%
	(O)revenue	54596020	0	0.00%	317691	0.58%
	Odakyu	0.995				
	(I)cost	95105070	-442591	-0.47%	-247053	-0.26%
	(I)property	503547659	-2343361	-0.47%	0	0.00%
	(O)revenue	117599098	0	0.00%	274274	0.23%
	Keihan	0.971				
	(I)cost	46034077	-1328346	-2.89%	-736796	-1.60%
	(I)property	199915154	-5768692	-2.89%	0	0.00%
	(O)revenue	54517737	0	0.00%	798088	1.46%

	DMU	Score(θ*)	CD Projection		Stepwise-DFM Projection	
	I/O	Data	Difference	%	Difference $d_{mn}^{x*}+s^{-**}$ $d_{so}^{y*}+s^{+**}$	%
E6	Tobu	0.950				
	(I)cost	137242584	-6805930	-4.96%	-4086177	-2.98%
	(I)property	712422107	-35329378	-4.96%	0	0.00%
	(O)revenue	160818200	0	0.00%	4088914	2.54%
	Sendai	0.962				
	(I)cost	9547699	-363129	-3.80%	-185084	-1.94%
	(I)property	123357198	-74728153	-60.58%	-73785469	-59.81%
	(O)revenue	11356883	0	0.00%	220156	1.94%
E7	Meitetsu	0.972				
	(I)cost	76843610	-2154485	-2.80%	-1104073	-1.44%
	(I)property	409977161	-11494638	-2.80%	0	0.00%
	(O)revenue	87543953	0	0.00%	1244695	1.42%
	Sapporo	0.982				
	(I)cost	31887493	-567949	-1.78%	-293748	-0.92%
	(I)property	406895116	-7247223	-1.78%	0	0.00%
	(O)revenue	37242789	0	0.00%	334647	0.90%
E8	Nagoya	0.960				
	(I)cost	61326002	-2479943	-4.04%	-1321222	-2.15%
	(I)property	780732042	-31571779	-4.04%	0	0.00%
	(O)revenue	68722164	0	0.00%	1418192	2.06%
E9	Tokyo	0.999				
	(I)cost	112204498	-75066	-0.07%	-37545	-0.03%
	(I)property	1692909251	-265406432	-15.68%	-264928768	-15.65%
	(O)revenue	125652692	0	0.00%	42045	0.03%
E10	Yokohama	0.962				
	(I)cost	28808045	-1096260	-3.81%	-558762	-1.94%
	(I)property	735299032	-317191579	-43.14%	-309081955	-42.03%
	(O)revenue	31033162	0	0.00%	601920	1.94%
	Kobe	0.854				
	(I)cost	18685348	-2720599	-14.56%	-1467105	-7.85%
	(I)property	309292607	-68421060	-22.12%	-49508705	-16.01%
	(O)revenue	17878193	0	0.00%	1403730	7.85%
	Fukuoka	0.923				
	(I)cost	22083430	-1692194	-7.66%	-879805	-3.98%
	(I)property	491943185	-184286067	-37.46%	-172028986	-34.97%
	(O)revenue	22835214	0	0.00%	909757	3.98%
E11	Kyoto	0.753				
	(I)cost	29271536	-7222361	-24.67%	-5399466	-18.45%
	(I)property	494381778	-121982117	-24.67%	0	0.00%
	(O)revenue	21196930	0	0.00%	2983043	14.07%

The Stepwise-DFM model is able to present a more realistic efficiency-improvement plan, which we compared with the results of Tables 2 and 3. For instance, the DFM results in Table 2 show that Fukuoka should reduce the Operating cost by 14.61 per cent and the Railway business property by 84.27 per cent, an increase in the Operating revenues of 14.61 per cent in order to become efficient. On the other hand, the Stepwise DFM results in Table 3 show that a reduction in Operating cost of 3.98 per cent and Railway business property of 34.97 per cent, and an increase in the Operating revenues of 3.98 per cent are required to become efficient. The Stepwise DFM model provides the policy decision-maker with practical and transparent solutions that are available in the DFM projection to reach the nearest upper level efficiency frontier.

Finally, the stepwise efficiency improvement projection results for all level efficient frontiers of Kyoto (last efficiency level DMU; E11) based on the CD and Stepwise-DFM model are presented in Table 4, while a comparative result of the stepwise DFM model for Kyoto is presented in Figure 9.

Table 4 Stepwise-efficiency improvement projection results for all level efficient frontier of Kyoto City

DMU	Score(θ*)	CD Projection	CD-DFM Projection	DMU	Score(θ*)	CD Projection	CD-DFM Projection
I/O	Data	%	%	I/O	Data	%	%
E1	0.522			E6	0.609		
(I)cost	29271536	-47.82%	-31.43%	(I)cost	29271536	-39.12%	-24.32%
(I)property	494381778	-87.32%	-83.34%	(I)property	494381778	-53.43%	-42.10%
(O)revenue	21196930	0.00%	31.43%	(O)revenue	21196930	0.00%	24.32%
E2	0.545			E7	0.620		
(I)cost	29271536	-45.53%	-29.47%	(I)cost	29271536	-38.00%	-23.46%
(I)property	494381778	-82.85%	-77.79%	(I)property	494381778	-53.16%	-42.17%
(O)revenue	21196930	0.00%	29.47%	(O)revenue	21196930	0.00%	23.46%
E3	0.558			E8	0.646		
(I)cost	29271536	-44.24%	-28.40%	(I)cost	29271536	-35.38%	-21.49%
(I)property	494381778	-64.92%	-54.96%	(I)property	494381778	-51.29%	-40.82%
(O)revenue	21196930	0.00%	28.40%	(O)revenue	21196930	0.00%	21.49%
E4	0.571			E9	0.647		
(I)cost	29271536	-42.86%	-27.27%	(I)cost	29271536	-35.34%	-21.46%
(I)property	494381778	-78.56%	-72.71%	(I)property	494381778	-42.23%	-29.84%
(O)revenue	21196930	0.00%	27.27%	(O)revenue	21196930	0.00%	21.46%
E5	0.586			E10	0.753		
(I)cost	29271536	-41.44%	-26.13%	(I)cost	29271536	-24.67%	-18.45%
(I)property	494381778	-81.64%	-76.84%	(I)property	494381778	-24.67%	0.00%
(O)revenue	21196930	0.00%	26.13%	(O)revenue	21196930	0.00%	14.07%

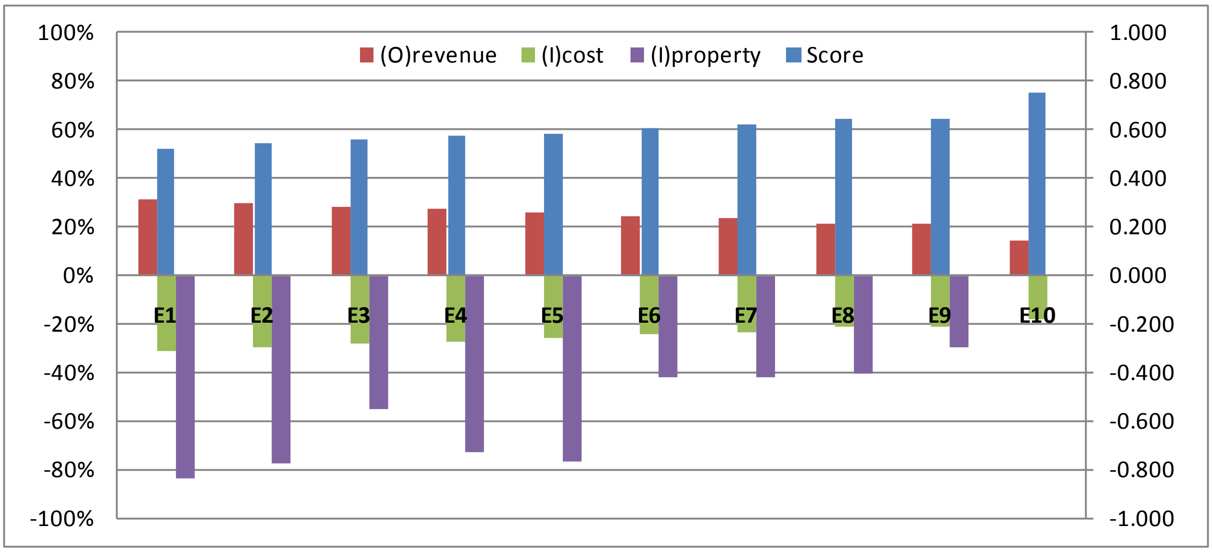

Figure 9 Efficiency improvement projection results based on the Stepwise-DFM model (Kyoto)

The findings from Figure 9 illustrate, for instance, that, if the Kyoto city wishes to implement an efficiency improvement plan with a E10 level, only a reduction in the operating cost of 18.45 per cent and an increase in operating revenue of 14.07 per cent are required, while then the efficiency level improves to the E10 level efficient frontier.

These results offer a meaningful contribution to decision support and planning for the efficiency improvement of public transport operations. In conclusion, this Stepwise DFM model may become a policy vehicle that may have great added value for decision making and planning of both public and private actors.

7. Conclusion

In this paper we have presented a new methodology, the Stepwise DFM model, which is integrated with a DFM and CD model. This new methodology does not require a uniform reduction of all inputs, as in the standard model. Instead, the new method minimizes the distance friction for each input and output separately. As a result, the reductions in inputs and increases in outputs do necessarily reach an efficiency frontier that is smaller than in the standard model. This offers more flexibility for the operational management of an organization. In addition, the stepwise projection allows DMUs to include various levels of ambition regarding the ultimate performance in their strategic judgment. In conclusion, our Stepwise DFM model is able to present a more realistic efficiency-improvement plan, and may thus provide a meaningful contribution to decision making and planning for efficiency improvement of relevant agents.

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