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Soushi Suzuki[1]
Peter Nijkamp[2]

[1] *Hokkai-Gakuen University, Department of Life Science and Technology, Japan;*
[2] *Faculty of Economics and Business Administration, VU University Amsterdam, and Tinbergen Institute.*

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A Stepwise Efficiency Improvement DEA Model for Airport Management with a Fixed Runway Capacity

Soushi Suzuki[a] Peter Nijkamp[b]

[a]*Hokkai-Gakuen University, Department of Life Science and Technology, Japan*
[b]*VU University Amsterdam, Department of Spatial Economics, and Tinbergen Institute, The Netherlands*

Abstract

Airports face a mutual competition. Consequently, they will be forced to improve the efficiency. Actual airport policies may comprise both short-term (flexible) adjustments and long-term (rigid) adjustments. Data Envelopment Analysis (DEA) is a standard tool to assess the relative efficiency. Two interesting approaches, namely Distance Friction Minimization (DFM) model and Context-Dependent (CD) model, are noteworthy here. DFM model serves to improve the performance of business activities by identifying the most appropriate movement towards the efficiency frontier surface. Likewise, CD model seeks to reach efficient frontiers in a series of steps. Stepwise DFM model is integrated of DFM and CD model. An extension of Stepwise DFM model is next achieved by including a fixed (rigid) input factor. In our study, the above-mentioned Stepwise Fixed Factor projection model is illustrated on the basis of a comparative study regarding an efficiency assessment of airports in Japan.

Keywords: Data Envelopment Analysis (DEA), Stepwise Projection, Distance Friction Minimization, Context-Dependent Model, Fixed Factor, Airport Operations
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1. Introduction

In the spirit of the deregulation movement, Japan is faced with an 'Asia Open Sky' agreement which favours liberalization in international airline services. This means an end to Japan's aviation policy of isolation. In association with this policy change, environmental concerns have also become increasingly urgent for small local or regional airports. Consequently, there is a need for an objective and transparent analysis of the performance and efficiency of airport operations in Japan.

A standard tool to judge the efficiency of such agencies is Data Envelopment Analysis (DEA). DEA was developed to analyze the relative efficiency of a 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 if a DMU plans to enhance its 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). Ever since, an avalanche of DEA-studies has been published. Seiford (2005) mentions some 2800 published articles on DEA. This large number of studies shows that comparative efficiency analysis has become an important topic.

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. For example, it is nearly impossible for one small local airport to be as efficient as one large metropolitan or regional airport (e.g., Tokyo HANEDA or Osaka ITAMI).

Recently, Suzuki and Nijkamp (2010) 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.

As a complementary approach, 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. Suzuki and Nijkamp (2011b) proposed in a recent study a Stepwise DFM model that is an integration of the DFM and the

CD model in order to design a stepwise efficiency-improving projection model for a conventional DEA. However, this model does not take into account a non-controllable or a fixed factor, caused by rigidity in input adjustment.

In the present study, we integrate the Stepwise DFM model with a fixed factor model which was originally proposed by Suzuki et al. (2011a) in order to adapt the DEA performance model to reflect realistic circumstances and requirements in an efficiency improvement projection. The above-mentioned stepwise fixed factor projection model will be illustrated on the basis of an application to the efficiency analysis of airport operations in Japan.

2. Efficiency Improvement Projection in DEA

In this section, we will highlight the basic elements of DEA. 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:

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

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

$$v_m \ge 0, \ u_s \ge 0,$$

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 the 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 $\left(\hat{x}_o, \hat{y}_o\right)$ can now be defined in (2.2) and (2.3) as:

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

$$\hat{y}_o = y_o + s^{+*}. \quad (2.3)$$

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).

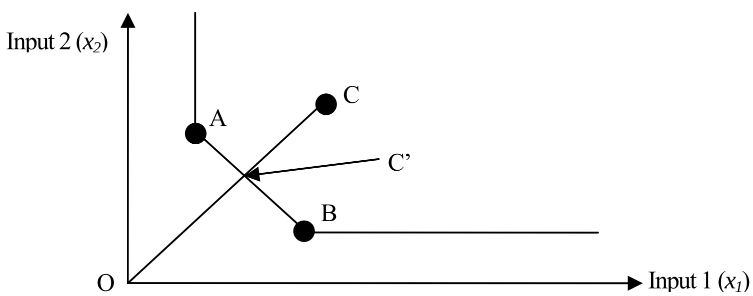

Figure 1 Illustration of original DEA projection in input space

3. The Distance Friction Minimization (DFM) Approach

This section will be devoted to a concise description of the Distance Friction Minimization (DFM) model. 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).

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.

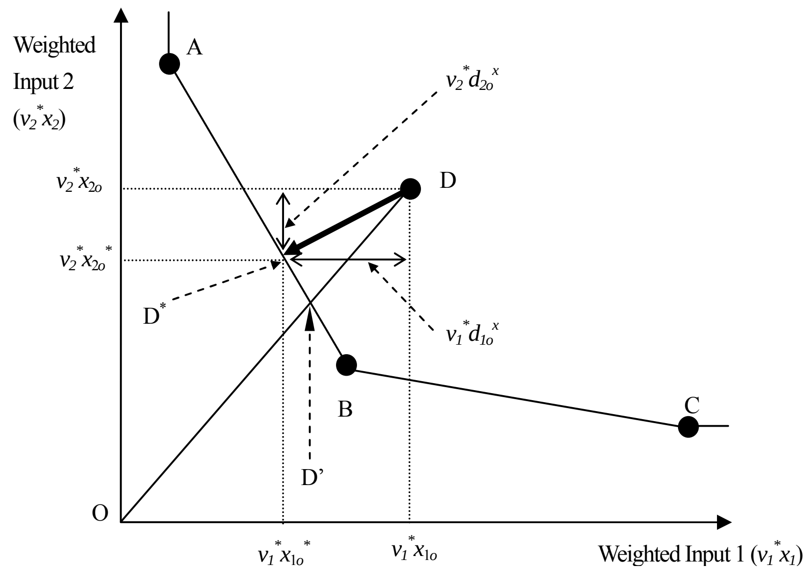

Figure 2 Illustration of the DFM approach (Input- $v_i^* x_i$ space)

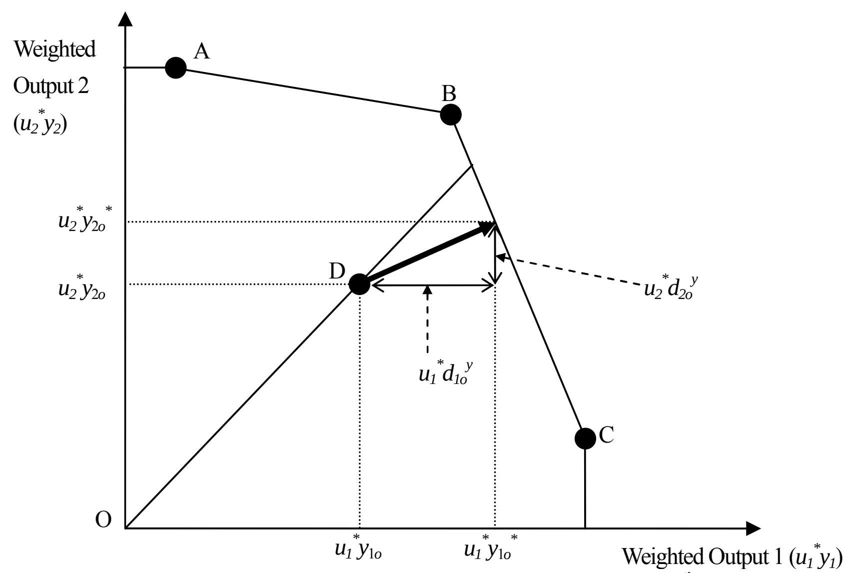

Figure 3 Illustration of the DFM approach (Output - $u_r^* y_r$ space)

In this study, we use the optimal weights u_s^* and v_m^* from (2.1), and then describe the 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 employed to assist a DMU to improve 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 employing a weighted Euclidean projection function, and, at the same time, it may address both input reduction and output increase. Here, we will only briefly describe the various steps.

First, the distance friction function Fr^x and Fr^y is specified by means of (3.1) and (3.2), which are defined by the Euclidean distance shown in Figures 2 and 3. Next, the following MOQP is solved 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:

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

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

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

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

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

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

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

where x_{mo} is the amount of input item m for any arbitrary inefficient $\mathrm{DMU_o}$, and y_{so} is the amount of output item s for any arbitrary inefficient $\mathrm{DMU_o}$. The constraint functions (3.3) and (3.4) refer to the target values of input reduction and output augmentation. The fairness in the distribution of contributions from the input and output side to achieve efficiency is established as follows. The total efficiency gap to be covered by inputs and outputs is (1-θ*). The input and the output side contribute according to their initial levels 1 and θ*, implying shares θ*/(1+θ*) and 1/(1+θ*) in the improvement contribution. Clearly, the contributions from both sides equal (1-θ*)[θ*/(1+θ*)], and (1-θ*)[1/(1+θ*)]. Hence, we find for the input reduction target and the output augmentation targets:

$$\text{Input reduction target: } \sum_m v_m^*\left(x_{mo} - d_{mo}^x\right) = 1 - \left(1-\theta^*\right)\times\frac{1}{\left(1+\theta^*\right)} = \frac{2\theta^*}{1+\theta^*}. \tag{3.8}$$

$$\text{Output augmentation target:: } \sum_s u_s^*\left(y_{so} + d_{so}^y\right) = \theta^* + \left(1-\theta^*\right)\times\frac{\theta^*}{\left(1+\theta^*\right)} = \frac{2\theta^*}{1+\theta^*}. \tag{3.9}$$

An illustration of the above situation is given in Figure 4.

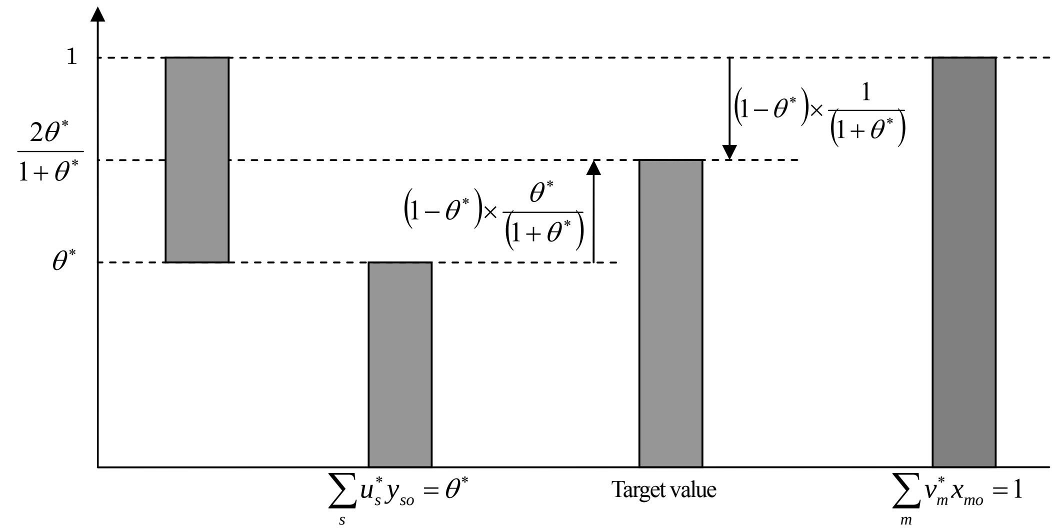

Figure 4 Presentation of a balanced allocation for the total efficiency gap

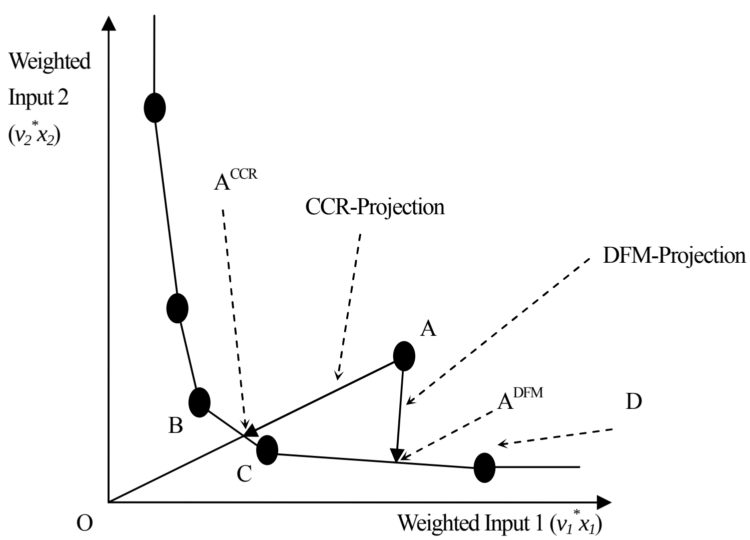

Figure 5 Degree of improvement of DFM and CCR projection in weighted input space

It is now possible to determine each optimal distance d_{mo}^{x*} and d_{so}^{y*} by using the MOQP model

(3.1)-(3.7). The friction minimization solution for an inefficient DMU_o can be expressed by means of formulas (3.9) and (3.10):

$$x^*_{mo} = x_{mo} - d^{x*}_{mo}; \tag{3.9}$$

$$y^*_{so} = y_{so} + d^{y*}_{so}. \tag{3.10}$$

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 5).

4. A Fixed Factor Model in DFM

Airport efficiency management is usually confronted with variable inputs (like labour force) and fixed inputs (like runway capacity). In the short run, runway capacity cannot be extended, and this limitation has to be incorporated in DEA. We now present a version of the DFM model that takes into account the presence of such fixed factors. The efficiency improvement projection, which incorporates a fixed factor (FF) in a DFM model, is presented in (4.1)-(4.7):

$$\min \; Fr^x = \sqrt{\sum_{m\in D}\left(v^*_m x_{mo} - v^*_m d^x_{mo}\right)^2} \tag{4.1}$$

$$\min \; Fr^y = \sqrt{\sum_{s\in D}\left(u^*_s y_{so} - u^*_s d^y_{so}\right)^2} \tag{4.2}$$

$$\text{s.t.} \; \sum_{m\in D} v^*_m\left(x_{mo} - d^x_{mo}\right) + \sum_{m\in ND} v^*_m x_{mo} = 1 - \frac{\left(1-\theta^*\right)\left(1 - \sum_{m\in ND} v^*_m x_{mo}\right)}{\left(1 - \sum_{m\in ND} v^*_m x_{mo}\right) + \left(\theta^* - \sum_{s\in ND} u^*_s y_{so}\right)} \tag{4.3}$$

$$\sum_{s\in D} u^*_s\left(y_{so} + d^y_{so}\right) + \sum_{s\in ND} u^*_s y_{so} = \theta^* + \frac{\left(1-\theta^*\right)\left(\theta^* - \sum_{s\in ND} u^*_s y_{so}\right)}{\left(1 - \sum_{m\in ND} v^*_m x_{mo}\right) + \left(\theta^* - \sum_{s\in ND} u^*_s y_{so}\right)} \tag{4.4}$$

$$x_{mo} - d^x_{mo} > 0 \tag{4.5}$$

$$d^x_{mo} \geq 0 \tag{4.6}$$

$$d^y_{so} \geq 0, \tag{4.7}$$

where the symbol $m \in D$ and $s \in D$ refers to the set of 'discretionary' inputs and outputs; and the symbols $m \in ND$ and $s \in ND$ refer to the set of 'non-discretionary' inputs and outputs.

The meaning of functions (4.1) and (4.2) is to consider only the distance friction of discretionary inputs and outputs. The constraint functions (4.3) and (4.4) are incorporated in the non-discretionary factors for the efficiency gap. The target values for input reduction and output augmentation with a balanced allocation depend on all total input-output scores and fixed factor situations as presented in Figure 6. The calculated result of (4.3) will then coincide with the calculated result of (4.4).

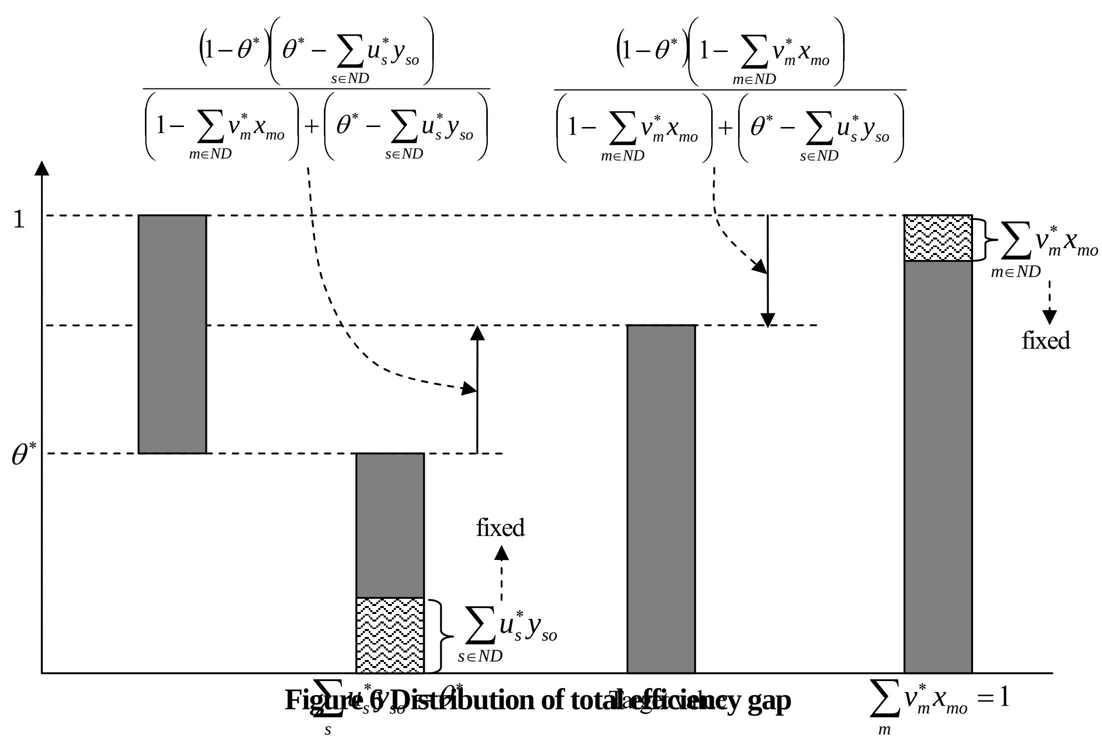

Figure 6 Distribution of total efficiency gap

Finally, the optimal solution for an inefficient DMU_o can now be expressed by means of (4.8) - (4.11):

$$x_{mo}^{**} = x_{mo} - d_{mo}^{x*} - s^{-**}, \quad m \in D \tag{4.8}$$

$$y_{so}^{**} = y_{so} + d_{so}^{y*} + s^{+**}, \quad s \in D \tag{4.9}$$

$$x_{mo}^{**} = x_{mo}, \quad m \in ND \tag{4.10}$$

$$y_{so}^{**} = y_{so}, \quad s \in ND \tag{4.11}$$

The slacks $s^{-**}, m \in ND$ and s^{+**}, $s \in ND$ are not incorporated in (4.10) and (4.11), because these factors are 'fixed 'or 'non-discretionary' inputs and outputs, in a way similar to the Banker and Morey (1986) model. This approach will hereafter be described as the DFM-FF approach.

5. Context-Dependent DEA

Next to the DFM model, there is also another approach that has gained quite some popularity over the past years. 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 (2.1).

When l = 1, it becomes the original CCR model, and the DMUs in set E1 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 El 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, J1. We then obtain the first-level efficient DMUs for set E1 (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 then obtain 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 7.

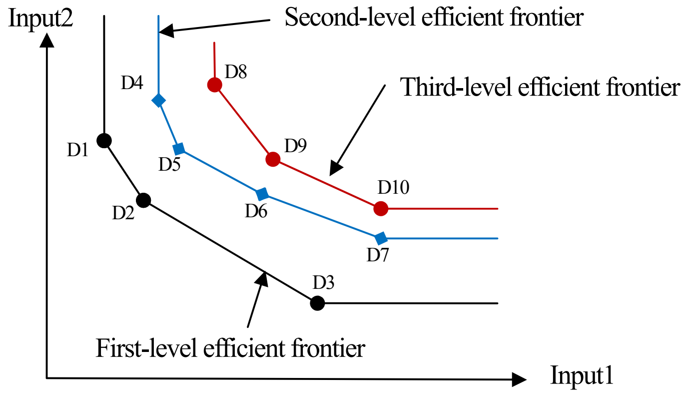

Figure 7 Illustration of the CD model

6. Stepwise DFM-FF Model in DEA

The DEA model used in an application forms a blend of the DFM-FF model and the CD model. Hence, we propose here a Stepwise DFM-FF model that is integrated with a DFM-FF and a 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 develop a new efficiency- improving projection model, which aims to integrate the CD model and DFM-FF approach to produce the 'Stepwise Distance Friction Minimization Fixed Factor' (hereafter Stepwise DFM-FF) model. It can yield a stepwise efficiency-improving projection incorporating a set of fixed input and output factors that depends on l -level efficient frontiers (l-level DFM projection), as shown in Figure 8.

For example, a second-level DFM-FF projection for DMU10 (D10) aims to position DMU10 on a second-level efficient frontier. And a first-level DFM-FF projection is just equal to a DFM-FF projection (4.1)-(4.7). Here, we observe that the second-level DFM-FF projection is easier to achieve than a first-level DFM-FF projection. A Stepwise DFM-FF model can yield a more practical and realistic efficiency-improving projection than a CCR Projection or a DFM-FF Projection.

The advantage of the Stepwise DFM-FF model is also that it yields an outcome on an l-level efficient frontier that is as close as possible to the DMU's input and output profile (see Figure 8). We will now illustrate the new model on the basis of an application to airline efficiency.

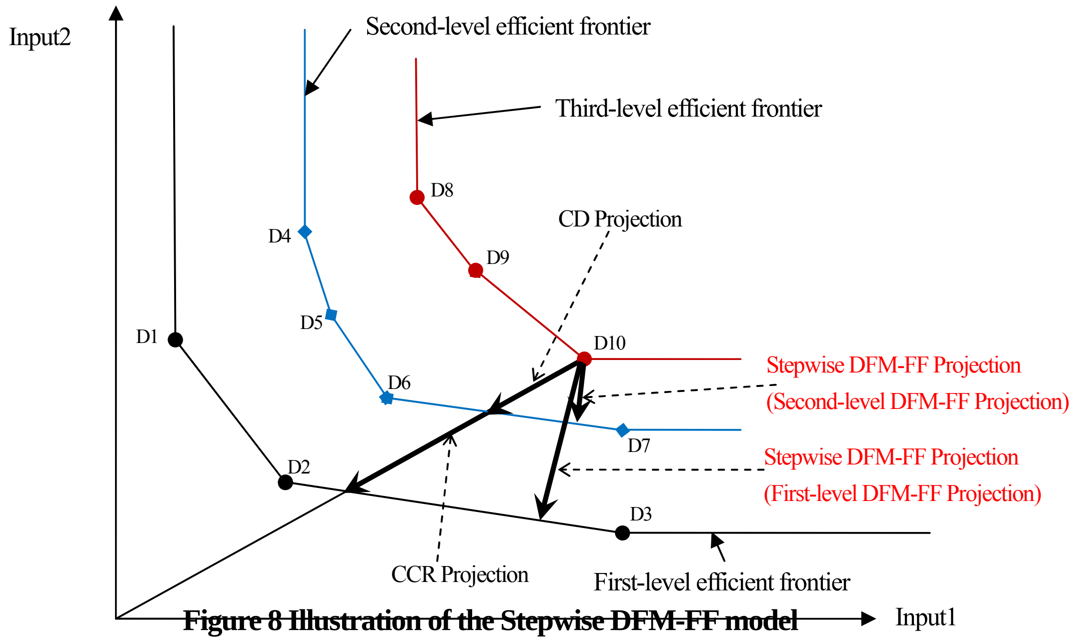

Figure 8 Illustration of the Stepwise DFM-FF model

7. Application of a Stepwise DFM-FF Model to Airport Efficiency Management in Japan

7.1 Database and analysis framework

DEA has found several applications in airport management studies. For applied airport studies based on DEA, we refer amongst others to Graham (2005) and Kamp et al. (2007) for a more extensive overview of the literature. These studies show that there is a lot of substantive and policy heterogeneity between such studies. Most studies using DEA to analyze airport efficiency use the number of passengers and the number of aircraft movements; these are usually seen as the ‘core activities’ of the airport. For example, Yoshida and Fujimoto (2004) analyse the efficiency of Japanese airports based on DEA using datasets of passenger loading, cargo handling, and aircraft movement for the output side; for the input side, runway length, terminal size, etc. are used. The factors mentioned above may be seen as ‘core activities’, It is worth noting that in recent years a dataset on management information regarding main airports in Japan has been disclosed. There is a fair chance that these data may be used to directly measure airport management efficiency by simultaneously considering input and output variables.

In our empirical work, we use input and output data for a set of 25 airports in Japan. The various DMUs used in our analysis are listed in Table 1.

Table 1 A listing of DMUs

No.	DMU	No.	DMU
1	Tokyo Haneda	14	Kochi
2	Osaka Itami	15	Kitakyushu
3	New Chitose (Sapporo)	16	Nagasaki
4	Fukuoka	17	Kumamoto
5	Okinawa	18	Ooita
6	Wakkanai	19	Miyazaki
7	Kushiro	20	Kagoshima
8	Hakodate	21	Okadama
9	Sendai	22	Komathu
10	Niigata	23	Miho
11	Hiroshima	24	Tokushima
12	Takamatsu	25	Misawa
13	Matsuyama		

In the present airport efficiency study we use the following inputs and outputs:

- Input:

  (I) Non-labour material costs (except employment costs) (in 2007) (approximated by Operating Costs);

  (I) Labour input (in 2007) (approximated by Employment Costs);

  (IF) Total runway length (in 2007);

- Output:

  (O) Operating airport revenues (in 2007).

All data were obtained from the Revenue and Expenditure 2007 database of the Ministry of Land, Infrastructure, Transport and Tourism in Japan. It should be noted that the DFM model retains the property of the standard DEA approach that the measurement units of the different inputs and outputs used need not to be identical, so that varying input and output measures can be employed. Some inputs or outputs may have a fixed character, implying that they cannot be changed in direct or flexible strategies to improve overall airport efficiency. This inertia is an element that has to be taken into account in the efficiency analysis. In the present context, the Total runway length may be interpreted as a fixed factor. This factor cannot easily be changed, at least not in the short run. Clearly, other capacity constraints (such as gate congestion or additional airport facilities) may also be present, but unfortunately, these datasets are still not available in Japan.

In our application, we will first apply the standard CCR model, while next the results are used to determine the CCR and DFM-FF projections. In addition, we will also employ the CD model, and then the results can be used to determine the CD and Stepwise DFM-FF projections. Finally, these various results will be mutually compared.

7.2 Efficiency evaluation based on the CCR model

The efficiency evaluation results for the 25 airports based on the CCR model is given in Figure 9. From Figure 9, it can be seen that Tokyo Haneda, Osaka Itami, and Komathu are efficiently-operating airports. On the other hand, Wakkanai, Kushiro, Okadama and Miho have a low efficiency. It is noteworthy that Wakkanai, Kushiro, and Okadama are in Hokkaido prefecture which is the most northern part of Japan.

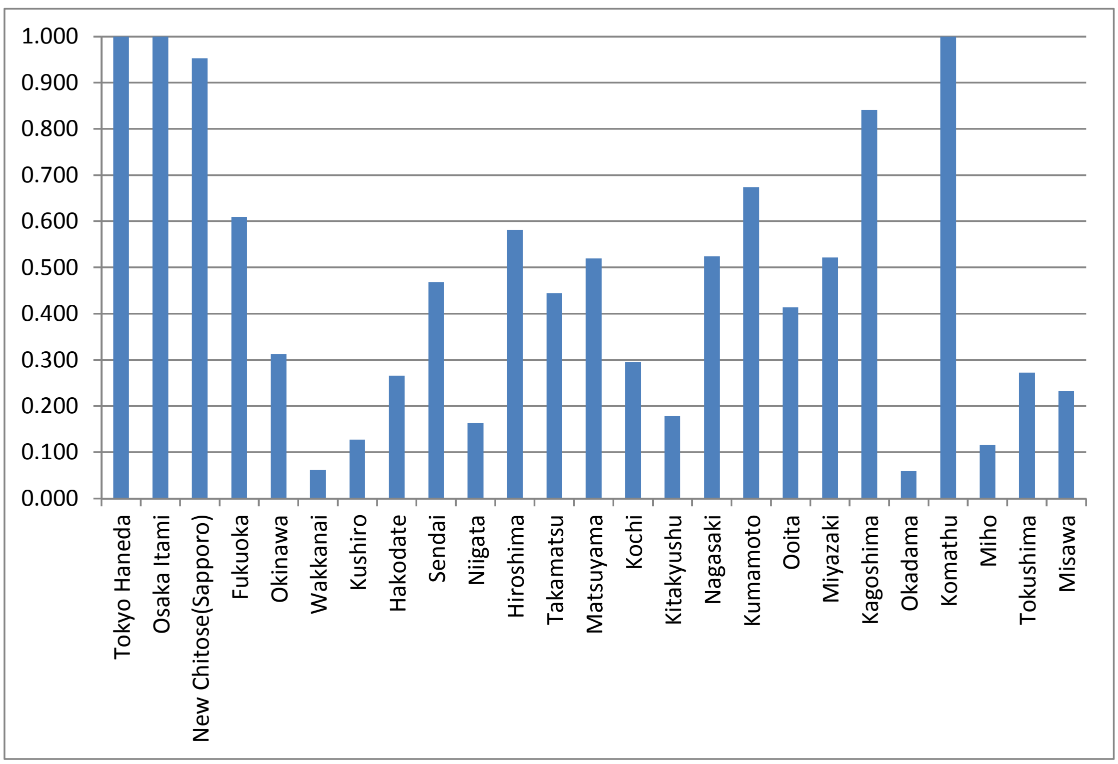

Figure 9 Efficiency score based on the CCR model

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

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

Table 2 Direct efficiency-improvement projection results of the DFM models (CCR)

		CCR-I model		DFM-FF model	
DMU	Score	Score(θ**)		Score(θ**)	
I/O	Data	Difference	%	Difference $d_{io}^{x*}-s^{-**}$ $d_{ro}^{y*}+s^{+**}$	%
New Chitose(Sapporo)	0.953	1.000		1.000	
(I)OC	6644	-311.5	-4.7%	-169.3	-2.5%
(I)EC	653	-208.1	-31.9%	-197.8	-30.3%
(IF)TRL	6000	-281.3	-4.7%	0.0	0.0%
(O)OR	9562	0.0	0.0%	243.7	2.5%
Fukuoka	0.609	1.000		1.000	
(I)OC	15577	-7266.5	-46.7%	-1936.4	-12.4%
(I)EC	629	-325.0	-51.7%	-129.9	-20.7%
(IF)TRL	2800	-1094.1	-39.1%	0.0	0.0%
(O)OR	10436	0.0	0.0%	6693.4	64.1%
Okinawa	0.312	1.000		1.000	
(I)OC	8084	-5564.0	-68.8%	-4913.1	-60.8%
(I)EC	624	-479.0	-76.8%	0.0	0.0%
(IF)TRL	3000	-2064.8	-68.8%	0.0	0.0%
(O)OR	3440	0.0	0.0%	2090.7	60.8%
Wakkanai	0.061	1.000		1.000	
(I)OC	988	-927.3	-93.9%	-988.0	-100.0%
(I)EC	109	-104.6	-95.9%	0.0	0.0%
(IF)TRL	2200	-2064.7	-93.9%	0.0	0.0%
(O)OR	107	0.0	0.0%	122.3	114.3%
Kushiro	0.127	1.000		1.000	
(I)OC	1772	-1546.7	-87.3%	-1610.6	-90.9%
(I)EC	165	-148.9	-90.3%	0.0	0.0%
(IF)TRL	2500	-2182.1	-87.3%	0.0	0.0%
(O)OR	362	0.0	0.0%	329.0	90.9%
Hakodate	0.266	1.000		1.000	
(I)OC	1982	-1454.9	-73.4%	-1335.9	-67.4%
(I)EC	148	-110.3	-74.5%	0.0	0.0%
(IF)TRL	3000	-2202.2	-73.4%	0.0	0.0%
(O)OR	857	0.0	0.0%	577.6	67.4%
Sendai	0.468	1.000		1.000	
(I)OC	2143	-1139.9	-53.2%	-911.6	-42.5%
(I)EC	346	-273.4	-79.0%	-253.2	-73.2%
(IF)TRL	4200	-2234.1	-53.2%	0.0	0.0%
(O)OR	1716	0.0	0.0%	730.0	42.5%
Niigata	0.163	1.000		1.000	
(I)OC	2594	-2171.0	-83.7%	-2359.5	-91.0%
(I)EC	131	-109.6	-83.7%	-63.8	-48.7%
(IF)TRL	3814	-3192.0	-83.7%	0.0	0.0%
(O)OR	651	0.0	0.0%	550.9	84.6%
Hiroshima	0.582	1.000		1.000	
(I)OC	1780	-744.8	-41.8%	-536.4	-30.1%
(I)EC	221	-146.6	-66.3%	-129.8	-58.7%
(IF)TRL	3000	-1255.3	-41.8%	0.0	0.0%
(O)OR	1717	0.0	0.0%	517.4	30.1%
Takamatsu	0.444	1.000		1.000	
(I)OC	998	-554.9	-55.6%	-469.5	-47.0%
(I)EC	114	-81.4	-71.4%	0.0	0.0%
(IF)TRL	2500	-1389.9	-55.6%	0.0	0.0%
(O)OR	804	0.0	0.0%	378.3	47.0%
Matsuyama	0.519	1.000		1.000	
(I)OC	1468	-705.6	-48.1%	-532.7	-36.3%
(I)EC	133	-78.2	-58.8%	-63.9	-48.1%
(IF)TRL	2500	-1201.7	-48.1%	0.0	0.0%
(O)OR	1267	0.0	0.0%	459.8	36.3%

		CCR-I model		DFM-FF model	
DMU	Score	Score(θ**)		Score(θ**)	
I/O	Data	Difference	%	Difference $d_{io}^{x*}-s^{-**}$ $d_{ro}^{y*}+s^{+**}$	%
Kochi	0.295	1.000		1.000	
(I)OC	1226	-863.9	-70.5%	-806.7	-65.8%
(I)EC	133	-106.7	-80.2%	0.0	0.0%
(IF)TRL	2500	-1761.5	-70.5%	0.0	0.0%
(O)OR	625	0.0	0.0%	411.2	65.8%
Kitakyushu	0.178	1.000		1.000	
(I)OC	2563	-2106.3	-82.2%	-2229.0	-87.0%
(I)EC	130	-106.8	-82.2%	-34.3	-26.4%
(IF)TRL	2500	-2054.5	-82.2%	0.0	0.0%
(O)OR	662	0.0	0.0%	515.4	77.9%
Nagasaki	0.524	1.000		1.000	
(I)OC	1282	-610.3	-47.6%	-505.9	-39.5%
(I)EC	118	-67.6	-57.3%	0.0	0.0%
(IF)TRL	4200	-1999.6	-47.6%	0.0	0.0%
(O)OR	1317	0.0	0.0%	519.7	39.5%
Kumamoto	0.674	1.000		1.000	
(I)OC	1294	-422.1	-32.6%	-296.0	-22.9%
(I)EC	120	-56.2	-46.9%	-45.6	-38.0%
(IF)TRL	3000	-978.6	-32.6%	0.0	0.0%
(O)OR	1551	0.0	0.0%	354.7	22.9%
Ooita	0.414	1.000		1.000	
(I)OC	1211	-710.2	-58.6%	-615.7	-50.8%
(I)EC	114	-77.2	-67.7%	0.0	0.0%
(IF)TRL	3000	-1759.3	-58.6%	0.0	0.0%
(O)OR	906	0.0	0.0%	460.7	50.8%
Miyazaki	0.522	1.000		1.000	
(I)OC	1716	-820.8	-47.8%	-607.8	-35.4%
(I)EC	136	-72.1	-53.0%	-55.1	-40.5%
(IF)TRL	2500	-1195.7	-47.8%	0.0	0.0%
(O)OR	1446	0.0	0.0%	512.2	35.4%
Kagoshima	0.841	1.000		1.000	
(I)OC	1608	-255.3	-15.9%	-156.4	-9.7%
(I)EC	366	-268.3	-73.3%	-260.6	-71.2%
(IF)TRL	3000	-476.2	-15.9%	0.0	0.0%
(O)OR	2290	0.0	0.0%	222.8	9.7%
Okadama	0.059	1.000		1.000	
(I)OC	597	-561.8	-94.1%	-597.0	-100.0%
(I)EC	77	-74.4	-96.6%	0.0	0.0%
(IF)TRL	1500	-1411.4	-94.1%	0.0	0.0%
(O)OR	64	0.0	0.0%	75.6	118.2%
Miho	0.115	1.000		1.000	
(I)OC	1650	-1473.2	-89.3%	-1333.0	-80.8%
(I)EC	56	-49.5	-88.5%	-44.4	-79.3%
(IF)TRL	2500	-2463.7	-98.6%	0.0	0.0%
(O)OR	222	0.0	0.0%	176.0	79.3%
Tokushima	0.273	1.000		1.000	
(I)OC	1367	-994.3	-72.7%	-547.8	-40.1%
(I)EC	55	-40.0	-72.7%	-36.7	-66.7%
(IF)TRL	2500	-2292.8	-91.7%	0.0	0.0%
(O)OR	497	0.0	0.0%	284.0	57.2%
Misawa	0.232	1.000		1.000	
(I)OC	292	-224.2	-76.8%	-182.0	-62.3%
(I)EC	88	-82.8	-94.1%	-79.6	-90.4%
(IF)TRL	3050	-2774.8	-91.0%	0.0	0.0%
(O)OR	143	0.0	0.0%	89.1	62.3%

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 Okinawa, Kushiro, Hakodate, Niigata, Takamatsu, Kochi, Kitakyushu, Nagasaki, Ooita and Tokushima, which are apparently non-slack type (i.e. s^{-**} and s^{+**} are zero) airports. The DFM-FF projection involves both an input reduction and output increase, and, clearly, the DFM-FF 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 Tokushima should reduce the Operating cost and the Employment cost by 72.7 percent and the Total runway length by 91.7 percent in order to become efficient. On the other hand, the DFM-FF results show that a reduction in the Operating costs of 40.1 percent and the Employment costs of 66.7 percent, and an increase in the Operating revenues of 57.2 percent are required to become efficient. This result shows that the DFM-FF projection can indeed be generated as a solution where Total runway length is fixed. 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.

7.4 Stepwise efficiency improvement projection based on the CD and Stepwise DFM-FF models

The efficiency-improvement projection results for the nearest upper-level efficient frontier based on the CD and Stepwise DFM-FF model for inefficient airports are presented in Table 3. In Table 3, it appears that the ratios of change in the Stepwise DFM-FF projection are smaller than those in the CD projection, as was expected. In Table 3, this particularly applies to Kumamoto, Miyazaki, Hiroshima, Matsuyama, Ooita, Hakodate, and Kochi, 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.

The Stepwise DFM-FF 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-FF results in Table 2 show that Hakodate should reduce the Operating cost by 67.4 percent, and increase the Operating revenues by 67.4 per cent in order to become efficient. On the other hand, the Stepwise DFM-FF results in Table 3 show that a reduction in employment costs of 11.1 percent, and an increase in the Operating revenues of 11.1 percent are required to become efficient. Note also that Total runway length is interpreted in the application as a fixed factor in both the DFM-FF and Stepwise DFM-FF model.

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

	DMU / I/O	Score / Data	CD model: Score(θ^{**}) Difference	CD model: %	Stepwise DFM-FF model: Score(θ^{**}) Difference $d_{io}^{x*}-s^{-**}$ / $d_{ro}^{y*}+s^{+**}$	Stepwise DFM-FF model: %
E3	Okinawa	0.487	1.000		1.000	
	(I)OC	8084	-4145.6	-51.3%	-4004.1	-49.5%
	(I)EC	624	-404.6	-64.9%	-277.8	-44.5%
	(IF)TRL	3000	-1538.5	-51.3%	0.0	0.0%
	(O)OR	3440	0.0	0.0%	1703.9	49.5%
	Kumamoto	0.878	1.000		1.000	
	(I)OC	1294	-158.1	-12.2%	0.0	0.0%
	(I)EC	120	-14.7	-12.2%	-8.7	-7.2%
	(IF)TRL	3000	-2053.0	-68.4%	0.0	0.0%
	(O)OR	1551	0.0	0.0%	100.9	6.5%
	Miyazaki	0.710	1.000		1.000	
	(I)OC	1716	-497.2	-29.0%	0.0	0.0%
	(I)EC	136	-39.4	-29.0%	-26.0	-19.1%
	(IF)TRL	2500	-1689.0	-67.6%	0.0	0.0%
	(O)OR	1446	0.0	0.0%	245.0	16.9%
	Kagoshima	0.990	1.000		1.000	
	(I)OC	1608	-16.8	-1.1%	-8.5	-0.5%
	(I)EC	366	-209.6	-57.3%	-208.8	-57.0%
	(IF)TRL	3000	-1563.1	-52.1%	0.0	0.0%
	(O)OR	2290	0.0	0.0%	12.0	0.5%
E4	Hiroshima	0.912	1.000		θ^{**}=1.000	
	(I)OC	1780	-155.9	-8.8%	0.0	0.0%
	(I)EC	221	-19.4	-8.8%	-17.7	-8.0%
	(IF)TRL	3000	-262.7	-8.8%	0.0	0.0%
	(O)OR	1717	0.0	0.0%	113.4	6.6%
	Matsuyama	0.893	1.000		1.000	
	(I)OC	1468	-156.6	-10.7%	0.0	0.0%
	(I)EC	133	-14.2	-10.7%	-14.7	-11.1%
	(IF)TRL	2500	-266.6	-10.7%	0.0	0.0%
	(O)OR	1267	0.0	0.0%	108.5	8.6%
	Nagasaki	0.864	1.000		1.000	
	(I)OC	1282	-183.2	-14.3%	-102.8	-8.0%
	(I)EC	118	-16.1	-13.7%	-8.6	-7.3%
	(IF)TRL	4200	-1652.6	-39.4%	0.0	0.0%
	(O)OR	1317	0.0	0.0%	96.5	7.3%
E5	Sendai	0.821	1.000		1.000	
	(I)OC	2143	-383.8	-17.9%	-220.3	-10.3%
	(I)EC	346	-137.3	-39.7%	-126.7	-36.6%
	(IF)TRL	4200	-752.1	-17.9%	0.0	0.0%
	(O)OR	1716	0.0	0.0%	176.4	10.3%
	Takamatsu	0.808	1.000		1.000	
	(I)OC	998	-191.5	-19.2%	-112.1	-11.2%
	(I)EC	114	-27.2	-23.9%	-24.3	-21.3%
	(IF)TRL	2500	-479.7	-19.2%	0.0	0.0%
	(O)OR	804	0.0	0.0%	90.3	11.2%
	Ooita	0.785	1.000		1.000	
	(I)OC	1211	-259.9	-21.5%	-291.3	-24.1%
	(I)EC	114	-24.5	-21.5%	0.0	0.0%
	(IF)TRL	3000	-643.9	-21.5%	0.0	0.0%
	(O)OR	906	0.0	0.0%	127.8	14.1%
	Tokushima	0.810	1.000		1.000	
	(I)OC	1367	-883.2	-64.6%	-832.3	-60.9%
	(I)EC	55	-10.5	-19.0%	-5.8	-10.5%
	(IF)TRL	2500	-915.0	-36.6%	0.0	0.0%
	(O)OR	497	0.0	0.0%	52.3	10.5%

	DMU / I/O	Score / Data	CD: Score(θ^{**}) Difference	CD: %	Stepwise DFM-FF model: Score(θ^{**}) Difference $d_{io}^{x*}-s^{-**}$ / $d_{ro}^{y*}+s^{+**}$	Stepwise DFM-FF model: %
E6	Hakodate	0.865	1.000		1.000	
	(I)OC	1982	-917.4	-46.3%	0.0	0.0%
	(I)EC	148	-20.0	-13.6%	-16.5	-11.1%
	(IF)TRL	3000	-406.4	-13.6%	0.0	0.0%
	(O)OR	857	0.0	0.0%	95.3	11.1%
	Kochi	0.736	1.000		1.000	
	(I)OC	1226	-449.0	-36.6%	0.0	0.0%
	(I)EC	133	-35.1	-26.4%	-31.7	-23.8%
	(IF)TRL	2500	-659.4	-26.4%	0.0	0.0%
	(O)OR	625	0.0	0.0%	149.0	23.8%
E7	Kitakyushu	0.927	1.000		1.000	
	(I)OC	2563	-1032.0	-40.3%	-911.3	-35.6%
	(I)EC	130	-15.7	-12.1%	-6.7	-5.1%
	(IF)TRL	2500	-182.6	-7.3%	0.0	0.0%
	(O)OR	662	0.0	0.0%	52.2	7.9%
	Misawa	0.961	1.000		1.000	
	(I)OC	292	-11.5	-3.9%	-5.9	-2.0%
	(I)EC	88	-57.6	-65.4%	-57.0	-64.7%
	(IF)TRL	3050	-2478.0	-81.3%	0.0	0.0%
	(O)OR	143	0.0	0.0%	2.9	2.0%
E8	Niigata	0.976	1.000		1.000	
	(I)OC	2594	-73.6	-2.8%	-42.8	-1.7%
	(I)EC	131	-3.2	-2.4%	-1.6	-1.2%
	(IF)TRL	3814	-1355.5	-35.5%	0.0	0.0%
	(O)OR	651	0.0	0.0%	7.9	1.2%
E9	Kushiro	0.848	1.000		1.000	
	(I)OC	1772	-329.6	-18.6%	-71.7	-4.0%
	(I)EC	165	-92.2	-55.9%	-79.1	-48.0%
	(IF)TRL	2500	-379.2	-15.2%	0.0	0.0%
	(O)OR	362	0.0	0.0%	64.7	17.9%
	Miho	0.798	1.000		1.000	
	(I)OC	1650	-765.4	-46.4%	-665.9	-40.4%
	(I)EC	56	-11.3	-20.2%	-6.3	-11.3%
	(IF)TRL	2500	-1199.4	-48.0%	0.0	0.0%
	(O)OR	222	0.0	0.0%	25.0	11.3%
E10	Wakkanai	0.530	1.000		1.000	
	(I)OC	988	-464.2	-47.0%	-303.4	-30.7%
	(I)EC	109	-60.2	-55.3%	-45.3	-41.5%
	(IF)TRL	2200	-1461.0	-66.4%	0.0	0.0%
	(O)OR	107	0.0	0.0%	32.9	30.7%
E11	Okadama	0.990	1.000		1.000	
	(I)OC	597	-6.0	-1.0%	-3.0	-0.5%
	(I)EC	77	-11.8	-15.3%	-11.5	-14.9%
	(IF)TRL	1500	-184.1	-12.3%	0.0	0.0%
	(O)OR	64	0.0	0.0%	0.3	0.5%

The Stepwise DFM-FF model provides the policy-maker with practical and transparent solutions that are available in the DFM-FF projection to reach the nearest upper-level efficiency frontier. These results offer a meaningful contribution to decision support and planning for the efficiency improvement of airport operations.

In conclusion, this Stepwise DFM-FF model may become a policy vehicle that may have great added value for the decision making and planning of both public and private actors. The particular merit of this approach is that it is able to include both flexible and rigid input variables.

8. Conclusion

In this paper we have presented a new methodology, the Stepwise DFM-FF model, which integrates a DFM-FF and a CD model. The new method minimizes the distance friction for each input and output separately and in a stepwise manner. As a result, the reductions in inputs and increases in outputs necessarily reach an efficiency frontier that is smaller than in the standard CCR model. Furthermore, the new model can incorporate a fixed factor (i.e., runway capacity), and then it could be adapted to reflect realistic conditions in an efficiency improvement projection. This would offer more flexibility for the operational management of an airport 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-FF model is able to generate a more realistic efficiency-improvement plan, and may thus provide a meaningful contribution to decision making and planning for the efficiency improvement of the relevant agents.

There is still a considerable research challenge ahead of us. Future research may address such topics as the integration of the Assurance Region Method (Dyson and Thanassoulis, 1988) or the Reference Point Model (Joro et al., 1998), which would make it possible to search freely on the efficient frontier for good solutions or for the most preferred solution based on the decision maker's preference structure. Another research challenge might be to make a more precise and gradual differentiation among the degree of flexibility (or rigidity) of input variables.

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