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Airline company's resource reallocation using network centralized data envelopment analysis with slack-based measure

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Abstract

Purpose – Since airlines that employ their resources effectively will achieve operating profitability, air route resource allocation is significant for airlines. This study aims to investigate an appropriate model to reallocate resources into each air route of an airline company.

Design/methodology/approach – This study proposes a network centralized data envelopment analysis (DEA) models with slack-based measure (SBM). The proposed model not only takes into account the two interconnected stages but also considers the nonradial approach with transfer-in and transfer-out slacks for resource reallocating. Furthermore, the authors modify the objective function to an input-oriented function with SBM, and divide the model into passenger and freight parts, which makes the model more realistic for the characteristic of air routes.

Findings – The empirical analysis using an airline company's internal data provides airline operators with information on how they increase or decrease input resources, which can serve as a practical guideline of resource reallocation. Specifically, the results indicate that the airline company should increase their input resources into long-haul air routes such as KOR-OCN while decreasing their input resources into short-haul air routes such as Korean-Oceania (KOR-OCN), Korean-Chinese (KOR-CHN), Korean-Southeast Asian (KOR-SEA), Korean-Japanese (KOR-JPN).

Originality/value – Although some papers evaluate air route efficiencies based on the DEA approach, a few existing papers have addressed resource allocation for air routes. This paper is the first to study the resource reallocation for air routes based on the DEA approach, contributing to the literature in expanding the scope of research on resource reallocation.

Keywords Network centralized DEA, Air route, Resource reallocation, Resource utilization

Paper type Research paper

1. Introduction

The airline companies have been challenged with many events, such as the severe acute respiratory syndrome (SARS) outbreak in 2003, global financial crisis of 2008 and the expansion of the low-cost carriers (LCC), within and beyond the air transport industry (Low and Lee, 2014). Due to COVID-19, for example, the overall passenger load factor in 2020 was on average 17.8% points

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lower than in 2019, at 64.8% (IATA, 2020). To survive in these environments, making a profit from scarce resources is crucial for airline companies. Therefore, airlines should identify and improve the less efficient air routes to maintain their competitive advantages in the marketplace (Chiou *et al.*, 2012). Specifically, since the sum of each air route's profit contributes to the airline's overall profits, how to reallocate their resources into each air route is the most significant for airlines.

To appropriately handle the resource allocation problem, many researchers have developed a range of data envelopment analysis (DEA) models (Song *et al.*, 2019). DEA is a nonparametric approach for estimating the relative efficiencies of decision-making units (DMUs) (Maltseva *et al.*, 2020). The efficiency score is calculated by the distance from the frontier line, the outermost boundary of the production possibility set. DEA model has been a useful tool for resource allocation planning because it can suggest technically feasible production plans based on the slack values representing the distance from the frontier line to a DMU (Ang *et al.*, 2020). Thus, many researchers have addressed the resource allocation problems in many research fields using DEA-based methodologies. Song *et al.* (2019) proposed an adjusted meta-frontier DEA for resource allocation and estimated the amounts of natural resource reduction in China at a regional level. Wu *et al.* (2016) developed a free allocation of emission reduction tasks (AERT) mechanism based on the DEA approach and addressed specific emission reduction problems. Du *et al.* (2014) and Chu *et al.* (2020) utilized DEA methodology to handle the fixed cost and resource allocation. However, since traditional DEA approaches set targets separately for each DMU, they are not suitable for the situation in which a central organizer/organization manages all the DMUs. Therefore, Lozano and Villa (2004) developed a centralized DEA (CDEA) to maximize the efficiency of individual units while the overall output production is maximized or the overall input consumption is minimized. Following the previous literature, various research has been conducted using the CDEA, and some research has also been conducted in the transportation sector. For instance, Chen *et al.* (2018) and Yu and Chen (2016) dealt with container shipping companies' resource allocation problems using the adjusted CDEA model. The DEA models in the papers aim to increase revenue while decreasing emission levels among shipping routes.

This study aims to investigate an appropriate model to optimize resource allocation for each air route of an airline company. While the standard DEA models usually use the one-directional slack to calculate the efficiency score, we utilize two-directional slack to address the resource reallocation problem based on CDEA model. The proposed model structure consists of the two-stage process (allocation and transport) based on the characteristics of air routes. Furthermore, we modify the objective function to an input-oriented function with slack-based measure (SBM) and add resource allocation rule in the model, which can reflect the airline's decision-making process. The research result illustrates how the airline company reallocates their input resources across the air routes from the slack values.

2. Literature review

2.1 Resource reallocation planning

The problem of resource reallocation is dealt with in a variety of research fields, including the transportation sector. Several studies have figured out the problem using optimization methods. Lu and Mu (2016) analyzed a slot reallocation problem for containership schedule adjustment, developing an integer programming model. The proposed model aims to maximize a shipping line's benefit under a given adjusted schedule. Taking into account the customer satisfaction for the mathematical algorithm, Ko *et al.* (2020) worked out the optimal airline seat reallocation planning. Adjusting several types of objective functions in a numerical example, they validate their optimization model reflecting customer dissatisfaction levels. Lagerholm *et al.* (2000) explored the airline crew scheduling problem within artificial neural network (ANN) algorithm framework. In order to minimize labor costs associated with a schedule of flight as well as the total crew waiting time, they tested the proposed algorithm on two-real world problems. Andréasson (2003) solved the reallocation problem of empty personal rapid transit (PRT) vehicles using three stages model. In the empirical analysis, this study applied the model to a PRT network to reduce passengers' average waiting time. Besides optimization models, as I mentioned before, many scholars have employed CDEA model to handle the resource reallocation problem. Chang *et al.* (2015) analyzed a container terminal operator's resource allocation problems using transfer-in and transfer-out input slacks. Under minor and major scenarios, the results of optimal input slack values provided reallocation strategies about how much input resources (the amount of hauling equipment and labor) should be reduced and transferred among several container terminals to enhance the overall performance. Lozano *et al.* (2011) applied the CDEA model under a capital budget constraint to the Spanish Port Agency which operates 28 Spanish ports. The results showed that the total output could increase without additional resources by input reallocation. Yu *et al.* (2013) conducted an empirical analysis on human resources reallocation in Taiwan's airports. This study included the number of regular and contracted employees in input variables and offered suggestions for efficiently allocating human resources among airports.

2.2 DEA models for airline operations

DEA models have been used in the airline industry to assess airline and air route performance. Initially, papers used standard DEA models to estimate the performance. However, with the development of various DEA models such as SBM-DEA (Tone, 2001), dynamic DEA (Färe and Grosskopf, 1997), and network DEA (Färe and Grosskopf, 2000), researchers have developed modified DEA models suitable for airlines' operational environment. Lozano and Gutiérrez (2014) suggested network DEA with slack-based measure (SBM-NDEA) to overcome single-process DEA models' problem that ignores internal processes in their production system. Comparing the results of SBM-NDEA with the results of single-phase SBM-DEA, they evaluated European airlines' efficiency, which shows the differences between the two models. Mallikarjun (2015) developed an unoriented NDEA model based on the airline's 3-stage operational structure: operation, service and sales stage. They adjusted the objective function of radial NDEA to consider both reductions of input and expansion of output in their model. To prove the utility of the proposed model, they conducted empirical analysis on the United States (US) domestic airlines and suggested that the efficiency of major airlines is significantly higher than national airlines on average. Zhu (2011) proposed an NDEA model with a centralized concept, addressing the conflicts between two stages. In the first stage, specifically, standard NDEA aims to increase the intermediate variable considered as output, and in the second stage, to decrease the intermediate variable considered as input. Based on empirical analysis, they showed the discriminate power of the proposed model with the assumption that both stages' objectivity was the same. The dynamic DEA includes variables that flow to the next period, called carry-over. Yu *et al.* (2019) and Omrani and Soltanzadeh (2016) each presented a dynamic NDEA (DNDEA) to evaluate the relative efficiency of airlines, which reflects dynamic changes in production processes. In those studies, the authors selected the number of fleet seat and the number of destinations as carry-over variables to consecutive periods, respectively. Chang *et al.* (2014) developed an SBM-DEA model with the weak disposability assumption in undesirable output constraints to estimate the environmental efficiency. They consider the dependent relationship between desirable and undesirable output by adding the assumption, reflecting the airline's operational environment. Shirazi and Mohammadi (2019) established a robust SBM-DEA under the assumption of uncertainty in outputs. They estimated the efficiency of Iranian airlines, considering the delays in airlines as undesirable output. Cui and Li (2015) and Wanke and Barros (2016) introduced the virtual frontier concept to existing DEA-based papers related to the assessment of airline efficiency. Virtual frontier is formed from reduced input references and expanded output references, thus reducing the number of efficient DMU, which can differentiate efficient DMUs from the original references.

Most of the papers related to the airline industry have proposed DEA models with minor/major modifications and focused on the estimation of airline efficiency, while a few papers focused on the estimation of air route efficiency. First of all, based on Charnes *et al.* (1978) (hereinafter CCR) and Banker *et al.* (1984) (hereinafter BCC) models, DEA Chiou and Chen (2006) measured the efficiency of each air route operated by a Taiwanese airline. They divided air routes' operational structure into two-stage, production and service, and measured each stage's efficiency separately. Yu and Chen (2011) proposed a fractional NDEA (FNDEA) that integrates the production and service process in a model for consistent performance estimation. Then, they conducted an empirical analysis using the data used in Chiou and Chen (2006) to compare the proposed model with Chiou and Chen (2006)'s separate multistage DEA model, thus attesting to the advantages of FNDEA model. Shao and Sun (2016) separated the operational process into allocation stage and transport stage that consists of two paralleled subfunction transport stages, passenger transport and freight transport. They proposed an NDEA model that assigns different weights for the intermediate variables to distinguish the input and output of the component.

2.3 Contributions of this paper

This paper fills academic gaps from the existing literature in the three following aspects. (1) Although some papers evaluate air route efficiencies based on the DEA approach (Chiou and Chen, 2006; Yu and Chen, 2011; Shao and Sun, 2016), only a few existing papers have addressed resource allocation for air routes. This paper is the first to study the resource reallocation for air routes based on the DEA approach. (2) Another contribution is that this paper proposes a new DEA model that takes account of both the network structure and SBM, making it suitable for dealing with route-based resource reallocation. Because the SBM approach directly addresses input excess and output deficit based on slack value (Tone, 2001), the proposed model can solve the traditional DEA model's problem of increasing (decreasing) all input (outputs) in a proportional way (lo Storto and Evangelista, 2022). Our model, in this regard, provides a reliable method for optimal resource allocation. (3) The empirical analysis using an airline company's internal data provides airline operators with information on how they increase or decrease input resources (the number of flights), which can serve as a practical guideline of reallocation for resource utilization.

3. Model for route-level resource reallocation

3.1 Conceptual structure of the model

The proposed model is developed under the CDEA, first expounded by Lozano and Villa (2004). Lozano and Villa (2004) introduced CDEA to optimize the overall consumption of the inputs and the overall production of the outputs. In CDEA, all DMUs are controlled by a centralized decision-maker who oversees all the DMUs. While conventional DEA models focus on how each DMU can reduce input or increase output by benchmarking the efficient DMU, CDEA considers projecting all DMU simultaneously to the frontier line for an entity's efficient resource allocation from the overall perspective. Since centralized decision-makers (DM) hope to optimize their organization's performance as a whole, the decentralized model is probably inappropriate for a centralized organization, such as an airline. For example, airlines that are the centralized decision-maker of each air route are interested in optimizing their overall resource consumption in all air routes rather than optimizing each air routes' resource consumption.

The CDEA constitutes two phases. In the first phase, all input dimensions are reduced at the same rate. Then, in the second phase, the slack values of input/output are sought for additional reduction of input/expansion of output. Let θ be radial contradiction of total input vector; $j, r = 1, 2, \ldots, n$, be indexes for DMUs; $i = 1, 2 \ldots, m$, be index for inputs; $k = 1, 2, \ldots, p$, be index for outputs; s_i, t_k be slacks along the input and output dimension i, k. The input-oriented and radial CDEA model can be expressed as follows:

Phase 1

$$\min \theta$$

$$s.t. \sum_{r=1}^{n} \sum_{j=1}^{n} \lambda_{jr} x_{ij} \leq \theta \sum_{j=1}^{n} x_{ij}, \forall i$$

$$\sum_{r=1}^{n} \sum_{j=1}^{n} \lambda_{jr} y_{kj} \geq \sum_{r=1}^{n} y_{kr}\ , \forall k$$

$$\sum_{j=1}^{n} \lambda_{jr} = 1, \ \forall r$$

$$\lambda_{jr} \geq 0, \ \theta\, free$$

Let θ^* be the optimum radial contradiction in the phase 1, then the phase 2 can be expressed as:

Phase 2

$$\max \sum_{i=1}^{m} s_i + \sum_{k=1}^{p} t_k$$

$$s.t. \sum_{r=1}^{n} \sum_{j=1}^{n} \lambda_{jr} x_{ij} = \theta^* \sum_{j=1}^{n} x_{ij} - s_i, \ \forall i$$

$$\sum_{r=1}^{n} \sum_{j=1}^{n} \lambda_{jr} y_{kj} = \theta^* \sum_{j=1}^{n} y_{kj} + t_k, \ \forall k$$

$$\sum_{j=1}^{n} \lambda_{jr} = 1, \ \forall r$$

$$\lambda_{jr}, s_i, t_k \geq 0$$

The traditional CDEA model is a useful methodology to handle resource reallocation problems in a centralized environment. However, there are three drawbacks that make it difficult to use for the resource reallocation among air routes. Firstly, the traditional model should minimize or maximize all inputs or outputs variables at the equal ratio due to the radial assumption (Chang *et al.*, 2021). More specifically, the classical input-oriented radial DEA uses the proportional reduction of input vectors approach, which ignores slacks while projecting each DMU to the frontier line (Tone, 2001). Secondly, the two-phase model developed by Lozano and Villa (2004) has different reference sets for each phase. Different reference sets of the models indicate inconsistencies in the intensity variable of the two-phase, which means that each phase evaluates the relative efficiency from different benchmarking points (Yu and Hsiao, 2018). Furthermore, a typical airline company generates capacity in the first stage, and the capacity is utilized as an input to produce service outputs in the second stage (Zhu, 2011). However, the traditional CDEA neglects the intermediate production process because it transforms first stage's inputs from a black-box to second stage's output

(Yu *et al.*, 2012). To solve these problems, this study proposes a single-phase slack-based network CDEA. The proposed model not only takes into account the two interconnected stages but also considers the nonradial approach with transfer-in and transfer-out slacks for resource reallocating.

3.2 Network centralized DEA model with slacks-based measures

3.2.1 Assumption and notations. Since air routes carry both passenger and freight transport, formulating a multiproduction process is adequate (Shao and Sun, 2016). Furthermore, the operational structure of the air route consists of two stages (allocation stage and transport stage) with input, intermediate products and output. This study combined the CDEA and network DEA model to reflect the characteristics of air route. Figure 1 depicts the air route's production process, and the model structure is generalized based on Shao and Sun (2016). The input resources include fuel consumption, number of flights, number of employees and others used for air route operations to produce the intermediate products. The intermediate products mean supply capacity such as available ton kilometer which is consumed for air routes service. The output originated from the service process represents the performance of air routes such as revenue ton-kilometers. According to the air routes' operational characteristics, we divide the model into the passenger transport and freight transport parts, showing the internal structure more clearly.

The following notations are defined to formulate the developed models.

n, m, h the number of air routes, common inputs, specific inputs

l^1, l^2 the number of intermediate products of passenger transport part, freight transport part

q^1, q^2 the number of outputs of passenger transport part, freight transport part

$j, r\,(j, r = 1, \ldots, n), i\,(i = 1, \ldots, m), f\,(f = 1, \ldots, \mathrm{h})$ indexes for air routes, common input, specific input

$k^1\,(k^1 = 1, \ldots, l^1)$, $k^2\,(k^2 = 1, \ldots, l^2)$ indexes for intermediate product of passenger transport part, freight transport part

$o^1\,(o^1 = 1, \ldots, q^1)$, $o^2\,(o^2 = 1, \ldots, q^2)$ indexes for output of passenger transport part, freight transport part

x_{ij}, x_{fj} the amount of common input i, specific input f for air route j

$z^1_{k^1 j}$, $z^2_{k^2 j}$ the amount of intermediate products k^1, k^2 for air route j

$y^1_{o^1 j}, y^1_{o^1 j}$ the amount of outputs o^1, o^2 produced by air route j

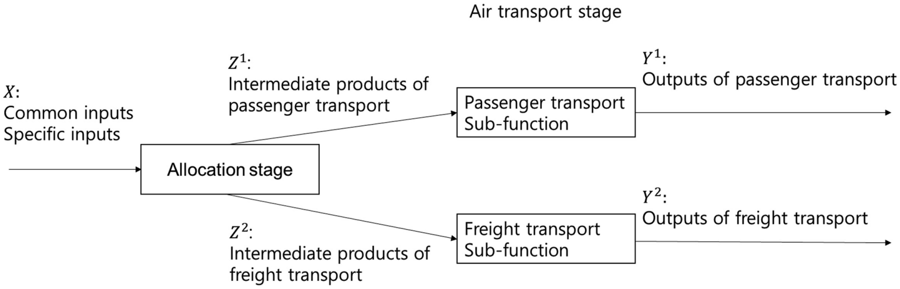

Figure 1.
Operational structure of air route

s_{ij}^{+}, s_{ij}^{-} the positive(transfer-in) slack, the negative(transfer-out) slack for common input *i* of air route j

$p_{o^1j}^{+}$, $p_{o^2j}^{+}$ the positive slack for outputs o^1, o^2 produced by air route j

$p_{o^1j}^{-}$, $p_{o^2j}^{-}$ the negative slack for outputs o^1, o^2 produced by air route j

λ_{jr}, μ_{jr}^{1}, μ_{jr}^{2} the intensity variables for projecting air route r at the corresponding stage

c_{ir} the limitation rate of resource reallocation

3.2.2 Modeling. When a company seeks to minimize input resource consumption while producing its current output levels, the input-oriented model is appropriate (Cullinane and Wang, 2006). The proposed model for air route resource reallocation is an input-oriented model that seeks to decrease input level for the given output level because airlines are interested in reallocating input resources that they can control. The proposed NCDEA model assuming variable return -to-scales (VRS) with the slack-based measure is formulated as follows:

(1) Objective function:

$$maixmize \sum_{r=1}^{n}\sum_{i=1}^{m}\left(s_{ir}^{-}-s_{ir}^{+}\right) \tag{1}$$

The objective function, Equation (1), ensures that the negative slack for input minus positive slacks for input will be maximized, which means that the overall input resources will decrease.

(2) Common input constraints:

$$\sum_{r=1}^{n}\sum_{j=1}^{n}\lambda_{jr}x_{ij}=\sum_{j=1}^{n}\left(x_{ij}+s_{ir}^{+}-s_{ir}^{-}\right),\ i=1,\ldots m \tag{2}$$

$$\sum_{j=1}^{n}\lambda_{jr}x_{ij}=x_{ir}+s_{ir}^{+}-s_{ir}^{+},\ r=1,\cdots,n,i=1,\ldots m \tag{3}$$

$$\sum_{j=1}^{n}s_{ij}^{+}\leq\sum_{j=1}^{n}s_{ij}^{-},\ i=1,\ldots m \tag{4}$$

Equation (2) implies that the overall input frontier is equal to the total reallocated inputs.

Equation (3) implies that the input frontier is equal to the observed amount of input resource for air route r. If the input resources are appropriately allocated, then the positive and negative slacks will be zero.

Equation (4) restricts the total amount of negative input slacks to larger than the total amount of positive slacks, which means that the total input resources i should be decreased.

(3) Specific input constraints:

$$\sum_{j=1}^{n}\lambda_{jr}x_{fj}\leq x_{fr},\ r=1,\cdots,m,f=1,\cdots,h \tag{5}$$

Equation (5) restricts the observed amount of specific input resources to larger than the overall specific input frontier, which means that the amount of specific input consumed from air route r should be fixed.

(4) Intermediate variables:

$$\sum_{j=1}^{n} \lambda_{jr} z^{1}_{k^{1}j} = \sum_{j=1}^{n} \mu^{1}_{jr} z^{1}_{k^{1}j},\ r = 1, \cdots, n,\ k^{1} = 1, \cdots, l^{1} \tag{6}$$

$$\sum_{j=1}^{n} \lambda_{jr} z^{2}_{k^{2}j} = \sum_{j=1}^{n} \mu^{2}_{jr} z^{2}_{k^{2}j},\ r = 1, \cdots, n,\ k^{2} = 1, \cdots, l^{2} \tag{7}$$

Equations (6) and (7) represent the "free link" relationship for intermediate products, which means that the linking activities are discretionally determined while maintaining continuity between inputs and outputs (Tone and Tsutsui, 2009).

(5) Output constraints:

$$\sum_{r=1}^{n} \sum_{j=1}^{n} \mu^{1}_{jr} y^{1}_{j} = \sum_{j=1}^{n} \left(y^{1}_{o^{1}j} + p^{+}_{o^{1}j} - p^{-}_{o^{1}j} \right),\ o^{1} = 1, \cdots, q^{1} \tag{8}$$

$$\sum_{j=1}^{n} \mu^{1}_{jr} y^{1}_{j} = y^{1}_{o^{1}r} + p^{+}_{o^{1}r} - p^{-}_{o^{1}r},\ r = 1, \cdots, n,\ o^{1} = 1, \cdots, q^{1} \tag{9}$$

$$\sum_{j=1}^{n} p^{-}_{o^{1}j} \leq \sum_{j=1}^{n} p^{+}_{o^{1}j},\ o^{1} = 1, \cdots, q^{1} \tag{10}$$

$$\sum_{r=1}^{n} \sum_{j=1}^{n} \mu^{2}_{jr} y^{2}_{j} = \sum_{j=1}^{n} \left(y^{2}_{o^{2}j} + p^{+}_{o^{2}j} - p^{-}_{o^{2}j} \right),\ o^{2} = 1, \cdots, q^{2} \tag{11}$$

$$\sum_{j=1}^{n} \mu^{2}_{jr} y^{2}_{j} = y^{2}_{o^{2}r} + p^{+}_{o^{2}r} - p^{-}_{o^{2}r},\ r = 1, \cdots, n,\ o^{2} = 1, \cdots, q^{2} \tag{12}$$

$$\sum_{j=1}^{n} p^{-}_{o^{2}j} \leq \sum_{j=1}^{n} p^{+}_{o^{2}j},\ o^{2} = 1, \cdots, q^{2} \tag{13}$$

Equations (8) and (11) imply that the overall output frontier is equal to the total output.

Equations (9) and (12) imply that the output frontier is equal to the observed amount of output resources for air router.

Equations (10) and (13) restrict the total amount of positive output slacks to larger than the total amount of negative output slacks, which means that the total outputs cannot be reduced.

(6) Reallocation rule:

$$c_{ir} * x_{ir} \leq x_{ir} - s^{-}_{ir} + s^{+}_{ir},\ r = 1, \cdots, n,\ i = 1, \ldots m \tag{14}$$

$$(1 + c_{ir}) * x_{ir} \geq x_{ir} - s^{-}_{ir} + s^{+}_{ir},\ r = 1, \cdots, n,\ i = 1, \ldots m \tag{15}$$

Equations (14) and (15) imply that the amount of reallocated input i from air route r cannot be increased/decreased more than c times the observed amount of input resource for air route r.

The constant c will be determined in advance, reflecting the conditions of each air route and input resource.

(7) VRS constraints:

$$\sum_{j=1}^{n} \lambda_{jr} = 1\,, \; \sum_{j=1}^{n} \mu_{jr}^{1} = 1, \sum_{j=1}^{n} \mu_{jr}^{2} = 1, \; r = 1, \ldots, n \tag{16}$$

Equation (16) represents the assumption of VRS in this model.

(8) Nonnegative variables constraints:

$$\lambda_{jr}\,,\, \mu_{jr}^{1}\,,\, \mu_{jr}^{2},\, s_{ir}^{+}\,, s_{ir}^{-},\, p_{o^1 j}^{+},\, p_{o^2 j}^{+} \geq 0,\;\; \forall j,\, r,\, o^{1}, o^{2}, \tag{17}$$

Equation (17) represent the non-negative constraints for any intensity variable and slack.

4. An application example using data from a Korean airline company

4.1 Data and variables

DMUs in this study are 74 scheduled international air routes to/from Incheon airport. The Airport code used in DMU is suggested in Appendix 1. Owing to the limited passenger air route data, we only consider direct flights in DMUs. This study conducts the analysis using semiannual data, as there is a major change in resource allocation for each air route by an airline company in every summer and winter season. This study analyzes the data of air routes in the 2019 summer season. After reviewing related literature, we select appropriate variables for applying the proposed model. Following variables from Shao and Sun (2016), we employ the number of flights that can reflect each air route's operating costs as the common input variable, the available seats and available freight tonnage as the intermediate variables, and the passenger throughput and freight throughput as output. The variable statistics are provided by an airline in Korea. The summary statistics related to all variables for the 74 air routes are presented in Table 1. In this empirical analysis, since there is a limit to know the conditions for the resource on each air route, the value of c_{ir} is set as 0.5 based on the test results.

4.2 Results of centralized resource reallocation in air routes

The proposed model aims to minimize the total amount of inputs' negative slack minus positive slack based on reallocation among each DMUs' input resources. In resource reallocation, inputs on any air route can be increased, but the overall input level should be decreased at the given output level. Since the proposed model is an input-oriented model, we will mainly describe the results of input resource reallocation. In terms of resource utilization, the closer a DMU's slacks to zero, the better a DMU's resources are being utilized. The followed two tables summarize the top 5 air routes with high value per negative and positive slack for input resources. The overall results of reallocation for input resources are shown in Appendix 2. The results of the positive slack for an input resource are shown in Table 2. The number of flights on the ICN/BNE should be increased by 125. The number of flights on the ICN/PRG should be increased by 124. The number of flights on the ICN/MAD and ICN/KMG should be increased by 122. The number of flights on the ICN/AKL should be increased by 121.

The results of the negative slack for an input resource are shown in Table 3. The number of flights on ICN/HKG route needs to be reduced by 1,064. The number of flights on ICN/BKK route needs to be reduced by 647. The number of flights on ICN/HAN and ICN/SGN route needs to be reduced by 642. The number of flights on ICN/PVG route needs to be reduced by 640.

The results of the resource reallocation are organized by continent to compare from the overall perspective. Table 4 indicates how many flights the centralized decision-maker needs to increase/reduce on which continent. Δx is the sum of negative slacks and positive slacks and we calculate the reallocation rate by dividing the number of flights before and after reallocation. Fewer Δx mean that the airline uses resources efficiently on the air routes. Hence, the closer the resource reallocation rate to one, the better the air routes' resources are employed. The optimum input resources for KOR-EUR routes are 1.02 times as large as the original level under the resource reallocation strategy, which is the closest to one. On the other hand, the optimum input resources for KOR-JPN routes are 0.57 times less than the original level under the resource reallocation strategy, which is the farthest from one. The results

Variables	Mean	SD	Max	Min
Input				
Number of flights	581.97	350.53	2,128	182
Intermediate product				
Available seats	158,210	107676.1	623,126	28,947
Available freight tonnage	6837.54	5687.75	30,215	265
Output				
Passenger throughput	129512.4	86043.47	443,031	20,436
Freight throughput(ton)	3968.56	3765.19	18684.52	8.01

Table 1. Summary statistics for all variables

Rank	Air route	Distance(km)	Positive slack for number of flights(s^+)
1	ICN/BNE	7,701	125
2	ICN/PRG	8,258	124
3	ICN/MAD	9,986	122
3	ICN/KMG	2,755	122
5	ICN/AKL	9,629	121

Table 2. Top5 E of input resources

Rank	Air route	Distance(km)	Negative slack for number of flights(s^-)
1	ICN/HKG	1,751	1,064
2	ICN/BKK	3,664	647
3	ICN/HAN	2,736	642
3	ICN/SGN	3,553	642
5	ICN/PVG	821	640

Table 3. Top5 air routes with negative slack from the reallocation results of input resources

	Before reallocation	Negative slack	Positive slack	Δx	After reallocation (rate)
KOR-AME	6,174	2,183	216	−1,967	4,207 (0.68)
KOR-CHN	12,846	5,516	302	−5,214	7,632 (0.59)
KOR-CIS	980	15	55	+40	1,020 (1.04)
KOR-EUR	4,856	429	546	+117	4,973 (1.02)
KOR-JPN	5,668	2,542	92	−2,450	3,218 (0.57)
KOR-OCN	970	15	246	+231	1,201 (1.24)
KOR-SEA	11,572	4,565	175	−4.390	7,182 (0.62)

Table 4. Results of reallocation for input resources by region

suggest that the resources are utilized most efficiently on KOR-EUR routes, while the resources are used most inefficiently on the KOR-JPN routes.

4.3 Implications

The research results show how the airline companies allocate their input resources based on the route level, suggesting some guidelines for reallocation strategies. Specifically, the results show that the airline company has to redistribute only a small amount of input resources into long-haul air routes such as KOR-EUR, KOR-CIS and KOR-OCN. On the contrary, the airline company has to reallocate a large number of input resources into short-haul air routes such as KOR-JPN, KOR-SEA and KOR-CHN. This suggests that the resource utilization level of those air routes is relatively lower than other air routes. Since the competition between full-service carriers (FSC) and LCC is getting more intense in the Korean air transportation market, especially for short-haul air routes, we assume that the severe competition between LCC and FSC has an impact on the research results. Based on the empirical result, the airline can easily pinpoint which air routes are operated inefficiently from the perspective of resource utilization and how they improve resource utilization by reallocating limited available resources across air routes.

5. Conclusion

This study aims to investigate an appropriate model to obtain implications for air routes resource reallocation from one airline company's perspective. By considering the two models, Network DEA with slack-based measure and CDEA, we proposed the adjusted model called network CDEA with slack-based measure that has more discriminative power than the classical CDEA approach. Furthermore, the proposed model was divided into passenger and freight parts, which makes the model more realistic for the characteristic of air routes. Since few papers have researched resource allocation for air routes using advanced DEA methodology, this study contributes to the literature in expanding the scope of research on resource allocation. In addition to the methodological point of view, this paper conducts an empirical analysis using a Korean airline company's air route data. Under the empirical results, the airline can improve their resource utilization by reallocating excess input resources, which causes the airline to enhance their operational efficiency of air routes. However, some air routes of the airline are not included due to the limited air route data in the current research. Moreover, since the focus of research is on proposing an adequate method for resource reallocation and how the proposed model is applied to an airline company, therefore, if the contributing factors toward the resource utilization of each air route are estimated, further research will be able to suggest various managerial implications.

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Appendix 1

Airport	City	Airport	City	Airport	City
AKL	Oakland	HKT	Phuket	PVG	Shanghai
AMS	Amsterdam	HND	Tokyo	RGN	Yangon
ATL	Atlanta	HNL	Honolulu	SEA	Seattle
BCN	Barcelona	IAD	Washington	SFO	San Francisco
BKK	Bangkok	IST	Istanbul	SGN	Ho Chi Minh
BNE	Brisbane	JFK	New York	SHE	Shenyang
BOM	Mumbai	KIJ	Niigata	SIN	Singapore
CAN	Guangzhou	KIX	Kansai	SVO	Moskva
CEB	Cebu	KMG	Kunming	SYD	Sydney
CGK	Jakarta	KTM	Kathmandu	SZX	Shenzhen
CGO	Zhengzhou	KUL	Kuala Lumpur	TAO	Qingdao
CNX	Chiang Mai	LAS	Las Vegas	TAS	Tashkent
CSX	Changsha	LAX	Los Angeles	TLV	Tel Aviv
DAD	Danang	LHR	London	TNA	Jinan
DEL	Delhi	MAD	Madrid	TPE	Taipei
DFW	Dallas	MNL	Manila	TSN	Tianjin
DLC	Dalian	MXP	Milano	ULN	Ulaanbaatar
DPS	Denpasar	NGO	Nagoya	VVO	Vladivostok
FCO	Rome	NRT	Narita	WEH	Weihai
FRA	Frankfurt	OKA	Okinawa	WUH	Wuhan
FUK	Fukuoka	OKJ	Okayama	XIY	Xian
GUM	Guam	ORD	Chicago	XMN	Xiamen
HAN	Hanoi	PEK	Beijing	YVR	Vancouver
HFE	Hefei	PNH	Phnum Penh	YYZ	Toronto
HKG	Hongkong	PRG	Prague		

Table A1.
Airport code

Appendix 2

Table A2.
Results of reallocation for input resources in each air route

Region	Route	Raw	Negative slack	Positive slack
KOR-OCN	ICN/AKL	292	0	121
KOR-EUR	ICN/AMS	328	134	0
KOR-AME	ICN/ATL	428	214	0
KOR-EUR	ICN/BCN	246	52	0
KOR-SEA	ICN/BKK	1,294	647	0
KOR-OCN	ICN/BNE	250	0	125
KOR-SEA	ICN/BOM	184	0	92
KOR-CHN	ICN/CAN	428	15	0
KOR-SEA	ICN/CEB	428	214	0
KOR-SEA	ICN/CGK	428	214	0
KOR-CHN	ICN/CGO	424	212	0
KOR-SEA	ICN/CNX	248	54	0
KOR-CHN	ICN/CSX	306	84	0
KOR-SEA	ICN/DAD	856	428	0
KOR-SEA	ICN/DEL	340	0	73
KOR-AME	ICN/DFW	304	0	109
KOR-CHN	ICN/DLC	638	319	0
KOR-SEA	ICN/DPS	550	275	0
KOR-EUR	ICN/FCO	426	213	0
KOR-EUR	ICN/FRA	428	15	0
KOR-JPN	ICN/FUK	1,270	635	0
KOR-SEA	ICN/GUM	856	428	0
KOR-SEA	ICN/HAN	1,284	642	0
KOR-CHN	ICN/HFE	292	0	71
KOR-CHN	ICN/HKG	2,128	1,064	0
KOR-SEA	ICN/HKT	428	15	0
KOR-JPN	ICN/HND	424	212	0
KOR-AME	ICN/HNL	434	217	0
KOR-AME	ICN/IAD	428	214	0
KOR-EUR	ICN/IST	730	0	111
KOR-AME	ICN/JFK	858	429	0
KOR-JPN	ICN/KIJ	184	0	92
KOR-JPN	ICN/KIX	1,272	636	0
KOR-CHN	ICN/KMG	244	0	122
KOR-SEA	ICN/KTM	184	0	10
KOR-SEA	ICN/KUL	428	15	0
KOR-AME	ICN/LAS	306	0	107
KOR-AME	ICN/LAX	856	428	0
KOR-EUR	ICN/LHR	428	15	0
KOR-EUR	ICN/MAD	672	0	122
KOR-SEA	ICN/MNL	860	430	0
KOR-EUR	ICN/MXP	680	0	97
KOR-JPN	ICN/NGO	852	426	0
KOR-JPN	ICN/NRT	852	426	0
KOR-JPN	ICN/OKA	388	194	0
KOR-JPN	ICN/OKJ	426	13	0
KOR-AME	ICN/ORD	428	15	0
KOR-CHN	ICN/PEK	858	429	0
KOR-SEA	ICN/PNH	428	15	0
KOR-EUR	ICN/PRG	248	0	124
KOR-CHN	ICN/PVG	1,280	640	0
KOR-SEA	ICN/RGN	424	11	0

(*continued*)

Region	Route	Raw	Negative slack	Positive slack
KOR-AME	ICN/SEA	424	212	0
KOR-AME	ICN/SFO	856	428	0
KOR-SEA	ICN/SGN	1,284	642	0
KOR-CHN	ICN/SHE	856	428	0
KOR-SEA	ICN/SIN	1,068	534	0
KOR-CIS	ICN/SVO	370	0	43
KOR-OCN	ICN/SYD	428	15	0
KOR-CHN	ICN/SZX	428	214	0
KOR-CHN	ICN/TAO	852	426	0
KOR-CIS	ICN/TAS	182	0	12
KOR-EUR	ICN/TLV	670	0	92
KOR-CHN	ICN/TNA	422	211	0
KOR-CHN	ICN/TPE	858	429	0
KOR-CHN	ICN/TSN	792	379	0
KOR-CHN	ICN/ULN	458	229	0
KOR-CIS	ICN/VVO	428	15	0
KOR-CHN	ICN/WEH	426	213	0
KOR-CHN	ICN/WUH	304	0	109
KOR-CHN	ICN/XIY	428	214	0
KOR-CHN	ICN/XMN	424	11	0
KOR-AME	ICN/YVR	428	15	0
KOR-AME	ICN/YYZ	424	11	0

Table A2.

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