THE SCALE EFFICIENCY MODEL OF AIRSPACE SECTOR CAPACITY

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Abstract

This study develops a measuring scale efficiency model of an air traffic controller to analyze the actual utility of airspace capacity and to realize the efficiency of airspace sector management. This study is basically on the key factors of air sector characteristic, air traffic composition, flight mix, and the procedure of air traffic control to analyze these factors and how they influence and relate to each other. Meanwhile, this research measures the relation between air traffic and airspace sector and with mathematical programming of data envelopment analysis to measure the efficiency of air sectors. The input variables are the number of hourly entry flight for each airspace sector, the number of hourly exit flight for each airspace sector, and the number of hourly flight entry/exit neighboring airspace sector for each airspace sector. The output variable is the number of hourly flight (hourly workload) for each airspace sector. The outcome shows that the hourly scale efficiency of the east airspace capacity in the Taipei terminal is better than the north and west sector. The after recombination outcome of improving hourly efficiency for airspace capacity is better than before recombination. Therefore, this model can be employed to study airspace sector planning strategies, and also can be used as a reference and tool to compare scale efficiency of sector capacity and differences between air routes and terminals.

Keywords: Scale efficiency, Airspace sector capacity, Data envelopment analysis.

Presenting Author's biography

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1 Introduction

Efficiency and safety, the Civil Aeronautics Administration in Taiwan follows the ICAO global airspace classification plan from 2001 to implement airspace classification for the Taipei Flight Information Region (FIR). In 2002 they followed ICAO's South China Sea route structure adjustment plan and made adjustments to the two international routes in the Taipei FIR, and connected with the routes of the Asia Pacific region. In the two years (2002~2003)[1] that followed ICAO's South China Sea regional RVSM (Reduced Vertical Separation Minimum) plan, they implemented RVSM for Taipei FIR, which increased the airspace capacity, and coordinated with Hong Kong, Naha, and Tokyo FIR to adjust the two parallel routes A1 and M750 to unidirectional routes. In 2002, Taipei FIR CNS/ATM (Communication, Navigation, Surveillance /Air Traffic Management) implementation Plan was put into place. The Civil Aeronautics Administration in Taiwan have invested massive funds and manpower to establish advanced air traffic control automation systems, to develop satellite-based navigation and digital communication technologies, to solve the near-saturation airport capacity and high density airspace usage problems, and to provide advanced air traffic services to domestic and international airlines. However, not only has the administration neglected the studies of which ways are the better approaches to improve the operational efficiency of airspace sector, but it has also given little consideration to develop a measuring model for assessment and analysis of airspace sector capacity to provide a initial, general demonstration and to suggest more efficient airspace utilities.

Thus, the air traffic management unit concerns air traffic flow control not only by the requirement for separation of safety, but also by a highly effective and system of air traffic flow management. There are many management strategies to moderately enhance airspace capacity and directly decrease flight delays, such as additional, technology and constructing new facilities, improving geometry of airways and flight levels, changing the procedure of air traffic control, improving navigation facilities and the sequence of take-off/landing. All of these improved methods involve both large budgets and environmental impact. Therefore, this study tries to cut down the managerial costs to propose a new approach, such as the adjustment of air traffic controller workload, flight take-off/landing sequences and flight separation time.

The above mentioned methods would increase and improve the operational efficiency of current airspace capacity in the short term. In view of increasing demand of international air aviation for passengers and air cargo, this will cause heavy workloads of controllers in some air routes and terminals to face a heavier burden. The air traffic controllers play an important role for the utility of airspace capacity. It is desirable to develop a measuring model of air sector efficiency to analyze the actual utility of airspace capacity, and to better understand the safety operations and efficiency of airspace operation. Thus, the purpose of this paper is to study airspace safety and efficiency to develop an appropriate measuring efficiency model of air traffic controller for predicting airspace capacity. This paper also considers the key factors of airspace sector characteristic, air traffic, flight mix, and the procedures of air traffic control for airspace capacity, and analyzes these factors influence each other in order to construct the model's variables.

Despite of measuring importance of airspace operational efficiency, a few extant studies have focused on airport operational efficiency but not on airspace. Hansen and Weidner (1995)[2] examine the efficiency of 14 multiple airport system regions in the US using the binary Logit model. Gillen and Lall (1977)[3] adopt data envelopment analysis (DEA) and Tobit models to measure and rank the productivity of 21 top US airports. Hooper and Hensher (1997)[4] adopt total factor productivity to measure airport performance at six Australian airports over three years. Vasigh and Hamzaee (1998) [5] assess the economic importance of seven US commercial airports using total factor productivity. Parker (1999) [6] use DEA to identify the sources of technical relative efficiency applied to former British Airport Authority (BAA), before and after privationation. Sarkis (2000, 2004) [7,8]examines 44 airports over a five period for operational efficiency by measuring their relative productivities as a ratio of outputs to inputs with performance measurement areas of infrastructure, environment, accessibility, capacity and investment. Martin and Roman (2001) [9] applied DEA method to analyze Spanish airports. Adler and Berechman (2001) [10] adopted the DEA to rank and examine western European airports and in particular how attractive these airports are to airlines. Fernandes and Pacheco (2002) [11] studies 33 Brazilian airports to identify and rank them according to the number of passengers processed using DEA. Bazargam et al., (2003) [12] also presents a productivity analysis using DEA of 45 US commercial airports selected from the top 15 large, medium and small hub airports to identify those airports that are not efficient and are thus dominated by other airports that are more efficient. Oum et al., (2003) [13] evaluates the overall productivity performance of airports including both airside and landside, explicitly taking into account the diverse nature of airport operations and market environments.

These studies focus on airports' productivity and efficiency performance, while largely ignoring the operation quality difference in airside or airspace service. Thus a major attractiveness of DEA is its ability to handle multiple inputs and outputs to derive the relative efficiencies and eliminates the difficult task of weight estimation. Therefore, this paper considers the merits of data envelopment analysis to a measure model of air controller's workload to evaluate current efficiency of airspace utilities. This paper first reviews literatures of measuring methods and key factors of operational efficiency in airspace sectors. These key factors are airspace sector characteristics, air traffic, flight mix, and the procedure of air traffic control for airspace capacity. Secondly, this paper analyzes these factors' mutual influence to construct the input and output variables and to assess operational efficiency of air sectors. Thirdly, this paper employed a mathematical programming methodology, and data envelopment analysis, to construct a measure model of air controller's workload, air sector characteristics, and air traffic demand and the utility efficiency of air sector capacity to evaluate operational efficiency of airspace sectors. Fourthly, the optimization model is used to analyze the Taipei terminal air control area. The objective function of this optimization model is set to measure the operational efficiency of air sector so as to analyze efficiency and issues between the air sectors' workload and air traffic, to check the related air sector size, issues of airspace management. Finally, the paper attempts to verify the suitability of the best optimal capacity through the data envelopment analysis and regression analysis.

2 Measuring scale efficiency of airspace sectors capacity

2.1 Data envelopment analysis literature reviews

Measuring airspace capacity is the basic foundation for researching airspace management problems. The core problems originate from conflict position, phase of flight, height of conflict, airspace structure, speed variation, type of conflict, weather, and traffic mix. The sector factors include including sector size, sector shape, boundary location, and airway configuration. Researching the proper estimation is important to the effects of management flow. Previous authors have suggested establishing different analyzing tools to assess the operation for air traffic management in airspace. Arnab Majumdar, Washington Ochieng and John Polak (2002) [14] provide a qualitative review of research on the effect of air traffic control, quality of equipment, individual difference and controller cognitive strategies to understand the relation between controller workload and theses factors. But the controller's workload is more difficult to define and even more difficult to measure [15]. That measuring approach must consider operation procedure specific to individual factors that influence the controller's response to be potentially difficult.

Previous researches have identified many factors that appear to influence the air sector capacity but do not capture the efficiency of air sector capacity. Therefore, this paper must clarify the efficiency terminology so that this paper can be more precisely used. Efficiency has several dimensions, two of which are economic efficiency and technological efficiency. Economic efficiency means that the firms (organizations) are using resources in such combinations that the cost per unit of output for that rate of output is the least. Technological efficiency means that it must not be possible to produce the same rate of output with less of any resource. The definition of operational efficiency is the use of input resources in the attainment of use of the airspace capacity outputs, in the context of the air traffic environmental factors. The definition of effectiveness is the attainment of pre-determined goals (maximum flight throughput). The definition of economy is keeping with pre-determined cost targets (inputs). We can combine these definitions into the equation: Achieved efficiency = Effectiveness × Economy × Planned efficiency [16], or $\frac{Actual\ outcome}{Actusal\ input} = \frac{Actual\ outcome}{Planned\ outcome} \times \frac{Planned\ inputs}{Actual\ inputs} \times \frac{Planned\ outcome}{Planned\ inputs}$ where inputs cover both resource and factors that aid the achievement of the output of capacity utility. A number of straightforward conclusions are made by taking the air traffic planning figures for each air sector and calculating the performance factor of air sector. In the single-input and single-output case, it is easy to see the airspace sector management depending on their point of view. In most cases, efficiency is not planned as such, since it is an unknown relationship between inputs and outputs. Therefore, this paper employed the frontier functions to measure and assess the per hour operation efficiency for each air sector. The per hour operational efficiency for each air sector is a decision-making unit. The efficiency measure of a decision-making unit is defined by its position relative to the frontier of best performance established mathematically by the ratio of weight sum of outputs to weighted sum of inputs. Therefore, this paper will apply data envelopment analysis, a very powerful tool, to evaluate the performance of per hour operational efficiency for current air sectors.

Data Envelopment Analysis (DEA) is an operation research-based method for measuring the performance efficiency of decision units that are characterized by multiple inputs and outputs. DEA converts multiple inputs and outputs of a decision unit into a single measure of performance, generally referred to as relative efficiency. While traditional approaches are more appropriate for macro-level analysis, DEA is a micro-level measurement tool that may have more managerial relevance. Charnes, Cooper, and Rhodes (1978) [17] were the first to propose the DEA methodology as an evaluation tool for decision units. Since then, DEA has been applied successfully as a performance evaluation tool in many fields including manufacturing, schools, banks, pharmacies, hospitals, and the airline business. DEA is a well-known technique in many fields that estimates the relative efficiencies of decision-making unit with common inputs and outputs. However, it has not been applied to air traffic control. DEA uses linear programming planning to get the optimal efficiency of decision-making units in an air sector, and then applies the dual problems approach to display the less efficient decision-making unit and to improve the input and output direction and range. It can be easily be solved using a linear programming software package. Therefore, this study proposes data envelopment analysis model to construct and measure the efficiency of each air sector's controllers.

In order to improve the service level of air traffic controllers, the issues related to measure air traffic controllers' flight management whether efficient or not needs to be addressed. Therefore, this study adopts the analysis of air traffic and sector factor data to measure the operational efficiency of air sectors. The efficiency is measured with the ratio of output and input and raising efficiency means to gain more output with an identical amount of input. Meanwhile, the fundamental goals of good service operations are punctuality, accuracy, and quality. Furthermore, the efficiency measurement is not only a relative value of the key factors of airspace system, controller's workload, flight density, flight mix, and the procedure of air traffic control for airspace capacity, and in advance setting the weight value of these key factors, but also uses the single ratio value to represent the efficiency of air sector controllers to improve actual air traffic management.

2.2 Setting up a performance system for efficiency of airspace sector capacity

In this section, this paper analyzes and explores a performance measuring system for each air sector to gain a better understanding of the process carried out measuring performance of air sectors, a mean for better control, and a knowledge of where and when management action is needed to improve performance of air sector.

This performance system of air sectors can provide an actual process to introduce analytical approach into the air sector's management information, and an ideal means to realize these benefits. It also provides a tool to aid in the evaluation of the quality of managerial control and decision-making unit at a local level of air sectors. These steps can cover the DEA highlighted reasons for an air sector unit's performance factors which contributed to, and detracted from, its efficiency rating. Meanwhile, this system also can find a unit's reference set a detailed qualitative comparison with the reference units and a unit's management style.

This paper considers identifying the unit objectives that must provide an efficiency objective of airspace planning and management to achieve high safety utility standards. Because per-hour traffic for each air sector is not always the same, there are many diversities, each air sector unit's hourly traffic can represent the role of utility or service efficiency of airspace sector. In order to better control the air traffic patterns and have a balanced flow in each air sector and effective utility of airspace capacity, this paper proposed per hour each air sector as a decision-making unit and identified what are the resources and limits of the units.

2.3 Choosing the output/input factors

In order to reflect and support the unit's objectives, thus this paper will choose suitable factors of per hour in each air sector as chosen output/input factors of the fourth step in figure 1. There are five important factors to influence the operational efficiency of air sector, namely air traffic controller, air traffic flow, air sector characteristics, weather conditions, and capacity facilities. This paper only studies the static operational efficiency of air sector, thus weather conditions and capacity facilities are not included. This paper includes all the important influencing factors of air sector capacity reported by Majundar (2002) and Sui-ling, Li [17,18]. These important factors are as follows: the variables of air traffic controller workload, air traffic flow, air sector characteristics factors. An air sector controller's workload is measured by the air traffic controllers to serve flights per hour entry/exit each air sector. Air traffic controller's workload is defined as flight number in the one hour time interval between the first flight entry time and the last flight exit time in each air sector per hour from a radar data. The air traffic flow factor is defined as the number of climbing aircraft in each air sector per hour, which includes descending, continuous cruising, cruise-climbing, cruise-descending, continuous descending, descend-climbing, continuous climbing, the difference of air flight level, and the difference of flight speed. Thus, an air sector characteristics may be composed of many variables, such as number of flight arrivals in each air sector per hour, number of flight departures, and number of neighboring sectors flight entry/exits certain variables are appropriate for particular countries.

2.4 The coefficient calculation on scale efficiency of airspace sector capacity

This study considers the decision making unit concept of data envelopment analysis to take into measuring model of operational efficiency per hour each air sector, so per hour each air sector is one decision making unit. The efficiency measure proposed by Charnes et al.,(1978)[17] maximizes weighted outputs over weighted inputs, subject to the condition that for every hourly air sector this efficiency measure is smaller than or equal to 1. Owing to a fractional programming program that is not easily solved, Charnes also shows how to transform following linear programming equivalent.

This paper is applied with Charnes, Cooper and Rhodes(CCR) model to calculate total technical efficiency of airspace sector capacity and Banker,Chames and Cooper(BCC)model to pure technical efficiency of airspace sector capacity, and then take the total technical efficiency over pure technical efficiency for each evaluated unit is scale efficiency of each evaluated unit.

2.5 Charnes, Cooper and Rhodes (CCR) model

Eq.(1) represents the maximum operational performance of total output. Eq.(2) represents that the performance of total input items must be equal to 1. Eq.(3) represents that difference between the maximum performance of total output items and the performance of total input items must be smaller than or equal to 1. Eq.(4) represents that the dummy variables of each output item must be larger than 0. Eq.(5) represents the dummy variable of each input item must be larger than 0.

$$Max \quad \sum_{r=1}^{s} U_r Y_{rk} \tag{1}$$

$$S.T. \quad \sum_{i=1}^{m} V_i X_{ik} = 1 \tag{2}$$

$$\sum_{r=1}^{s} U_r Y_{rk} - \sum_{i=1}^{m} V_i X_{ik} \leq 0, k = 1,...,n \tag{3}$$

$$U_r \geq \varepsilon > 0 \,; r = 1,...,s \tag{4}$$

$$V_r \geq \varepsilon > 0 \,; i = 1,...,m \tag{5}$$

Where,

X_{ik}: The input value for the unit k of i input items

Y_{rk}: The output value for the unit k of the r output items.

V_i: The dummy variable of per hour the i input item

U_r: The dummy variable of the r output item.

ε : A small positive value (=10^{-6})

2.6 Banker, Chames and Cooper (BCC) model

Eq.(6)- (11) is the Banker, Chames and Cooper (BCC) Model, If the value of Eq(1) is equal Eq.(6) represent the scale efficiency is optimal.

$$Max \quad \sum_{r=1}^{s} U_r Y_{rk} - U_k \tag{6}$$

$$S.T. \quad \sum_{i=1}^{m} V_i X_{ik} = 1 \tag{7}$$

$$\sum_{r=1}^{s} U_r Y_{rj} - \sum_{i=1}^{m} V_i X_{ij} - U_k \leq 0, k = 1,...,n \tag{8}$$

$$U_r \geq \varepsilon > 0 \,; r = 1,...,s \tag{9}$$

$$V_r \geq \varepsilon > 0 \,; i = 1,...,m \tag{10}$$

$$U_k \text{ no constraints; } j = 1,..., n \tag{11}$$

3 The proposed evaluated variables and scale efficiency model of airspace sectors capacity

3.1 The related variables for of airspace sectors capacity

There are five important variables to impact the efficiency of airspace sector capacity, which are air traffic controller, air traffic flow, air sector characteristics, weather conditions, and capacity facilities. This study only collects the air traffic flow, air sector characteristics variables for seven days of radar data in June and July 2005. Tab. 1 shows the relation coefficient of two variables between arrivalflights per sector and workload per sector is 0.8809. The coefficient of two variables between departure flights per sector and workload for per sector is 0.8318. The coefficient of two variables between entering other sector's flights and workload for per sector is 0.8457. Therefore, this study selects the higher relation coefficient between input and output variables, which are per hour workload of each sector, per hour arrival flight of each sector, per hour departure flight of each sector and per hour entering other sectors' flights of each sector. The input variables are per hour arrival flight of each sector, per hour departure flight of each sector and per hour entering other sectors' flights of each sector. The output variable is only per hour workload of each sector.

Tab. 1 The correlation coefficient of variables

	Workload	Arrival flights	Departure flights	Passing other sectors' flights
Workload	1			
Arrival flights	0.8809	1		
Departure flights	0.8318	0.4703	1	
Passing other sectors' flights	0.8457	0.9014	0.5214	1

3.2 The efficiency model of airspace sectors capacity

This paper is applied with CCR model to calculate total technical efficiency of airspace sector capacity

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and BCC model to pure technical efficiency of airspace sector capacity, and then take the total technical efficiency over pure technical efficiency for each evaluated unit is scale efficiency of each evaluated unit. The total technical efficiency model of airspace sector capacity is above mention Eq.(1) – (5).Where,

X_{ik}: The input value for per hour air sector k of the i input items (per hour arrival flights of each air sector , per hour departure flights of each air sector ,and per hour entering other air sector flights for each air sector)

Y_{rk}: The output value for per hour air sector k of the r output items (per hour workload of each air sector)

V_i: The dummy variable of per hour the i input variables of each air sector.

U_r: The dummy variable of per hour workload of each air sector r

ε : A small positive value (=10^{-6})

The pure technical efficiency model is above mention Eq.(6)-(11) is the Banker, Chames and Cooper (BCC) Model. Thus, every hour scale efficiency of per sector unit as follows Eq. (12) If the value of Eq(12) is equal i represent every hour scale efficiency of per sector unit is optimal.

$$SE_k = \frac{CCR_k}{BCC_k} \tag{12}$$

4 Case study

Along with the increasing air traffic and take-off/landing flights the Taipei terminal area is becoming very crowded. Thus the air traffic controllers and management bureau works under pressure. Therefore, this paper chooses the Taipei terminal control area to analyze the scale efficiency of air sector capacity.

4.1 The Characteristics of Taipei terminal control area

There are three sectors in the Taipei terminal control area, including east sector (ER), north sector (NR), and west sector (WR) as shown in Fig.1. North sector controls the flight take-off/landing at CKS airport. There are six take-off handoff points between Taipei terminal control area and Taipei Area Control Center, which is CHALI of air route A1 (south) and W4 (south), BAKER of air route B576, ANNA of air route A1 (north), ROBIN of air route R583 and M750 (north), GRACE of air route R595, and WADER of air route B591. There are six arrival handoff points, which is BRAVO of air route A1 (north) and W4 (north), BAKER of air route B576, ANNA of air route A1 (south), BRAVO of air route M750 (north), GRACE of air route R595, and WADER of air route B591. West sector control the flight departure at Sungshan airport. There are six departure handoff points between Taipei terminal control area and Taipei Area Control Center, which are HLG or XEROX of air route A1 (south) and W4 (south), or ROMEO of W4 (south), RONEY of air route W2, TONEY of air route W2 and W8, and WADER of air route B591. East sector control the flight arrival at Sungshan airport. There are four arrival handoff points, which is HLG of air route A1 (north) and W4 (north), TONEY of air route W2 and W8, and WADER or HAMMY of air route B591.

Fig. 1 The Air Sector's Configuration of Taipei Terminal Airspace

4.2 The scale efficiency of airspace sectors in Taipei terminal control area

This study collected seven days of radar data in June and July 2005 and these data are divided into north, west, and east three sectors. As the number of flights on the Thursday is the flight maximum among the seven days, and considers the flight activities decreased after 11 PM, this study analyzes only hourly data between 7 AM to 10 PM on Thursday. Therefore, this study selects 42 units of Thursday to evaluate per hour scale efficiency of air sectors. Meanwhile, this study also handles with the related input variables are the number of hourly arrival flights each air sector, number of hourly departure flights in each air sector, and number of hourly flight entry/exiting neighboring sectors in each air sector. The related output variables of the hourly workload serve flight entry/exits each air sector.

Tab. 2 shows the number of average arrivals /departures in the north sector is higher than the west sector and east air sector. The average hourly workload of east air sector is less than north and west air sector. The average hourly workload is not heavy and operation time is still surplus time in the east air sector. The average numbers of per hour arrival/departure flight of north and west air sectors are more than east air sector. The average numbers of hourly flight entry/exit neighboring sectors of the north air sector per hour are more than the west and east air sector.

Tab. 2 Flight hourly traffic characteristic in three sectors

Traffic characteristics	ER	NR	WR
Arrival flights	3	20	19
Departure flights	2	15	14
Other sectors' flights	10	25	12
Workload	15	45	31

This study takes as the input variables, which are the numbers of arrival flights in one hour for each sector, the numbers of departure flights in one hour for each sector, and the numbers of neighbor air sector hourly entry/exits each sector. The output variable is hourly workload in each sector, which represents hourly throughput flights in each sector. Taking both input-output data into the Data Envelopment Analysis model (BCC and CCR), which is operated by LINDO software. This study analyzes hourly data from 7 AM to 10 PM on Thursday, i.e. analyzing 16 hours for each air sector. A total of 42 hour units of air traffic data are analyzed. Tab. 3 shows that there are 9 hour units of air sectors to be scale efficiency and their operational efficiency performances are equal to 1. Tab. 3 shows these efficient hours are composed of 7 hours of the east air sector include the 10^{th}, 12^{th}, 16^{th}, 17^{th}, 19^{th}, 21-22^{th}hour, the 21^{th} hour of the north air sector, and the 21^{th} hour of the west air sector.

Tab. 3 The optimal number of evaluated 42 units

	ER	NR	WR
Optimal	7	1	1
No optimal	9	15	15

From DEA figures of total technical efficiency, pure technical efficiency, return to scale, and scale efficiency for evaluated 48 units to analyze which units are better condition. Tab. 4 also shows the average total technical efficiency, pure technical efficiency, return to scale, and scale efficiency of east sector is better than the others. The scale of the north and west sectors are decrease.

Tab. 4 The scale efficiency of airspace capacity

Taxonomy	ER	NR	WR
Total technical efficiency	0.959	0.964	0.981
Return to scale	0.977	2.655	1.528
Pure technical efficiency	0.966	0.996	0.989
Scale efficiency	0.991	0.967	0.991

4.3 Sensitivity analysis

These no efficiency performance of evaluated units can improve from reference optimal efficiency units include the 10^{th}, 12^{th}, 16^{th}, 17^{th}, 19^{th}, 21-22^{th}hour of east air sector, the 21^{th} hour of the north air sector, and the 21^{th} hour of the west air sector. The slack analysis of total technical efficiency for 48 evaluated units show as Tab. 5. Tab. 5 shows the evaluated units almost are refer to reference $12^{th}$of east sectors and $21^{th}$of west sectors.

Tab. 5 The frequency of best referenced units

ER							NR	WR
10^{th}	12^{th}	16^{th}	17^{th}	19^{th}	21^{th}	22^{th}	21^{th}	21^{th}
3	16	2	0	1	1	2	0	14

4.4 The prediction of per hour workload of air sectors

The outcome 48 unit can construct multiple regression models to predict per hour workload of air sector. Eq. (13) represents the estimator of per hour workload.

$$\hat{Workload}_k = 5.54 Arrival / departure + 15.16 RTS \quad (13)$$

(t=4.585) (t=19.797)

$$R^2 = 0.961, F = 563, N = 48$$

Where

$Workload$: per hour handle flights for each air sector

$Arrival / departure$: per hour rate of arrival and departure flights for each air sector

RTS : per hour return to scale for each air sector

4.5 The recombination strategies of airspace sector to improve airspace capacity

The DEA model of efficiency for per hour each air sector also can do advanced application or analysis the recombined sectors' strategies to compare with the efficiency performance of air sectors capacity before/after recombination. Therefore, this section proposes the concept to combine the air sector boundaries to analyze the efficiency of air sector recombination. This section will assess the efficiency of capacities in three sectors after recombination. There are two recombination strategies: one is recombination 1 to merge east and north air sector (ER+NR) as a new sector, the other is recombination 2 to merge the east and west air sector (ER+WR) as a sector. Tab. 6 shows the average efficiency of air sector before recombination is less than after recombination. This means the recombination of air sectors can improve and increase the efficiency performance of air sector. These outcomes mean the efficiency of Taipei terminal airspace after recombination 1 and recombination 2 are better than before recombination.

Tab. 6 the scale efficiency of airspace capacity for recombined sectors' strategies

Taxonomy	Resectorization 1		Resectorization 2	
	NR	ER+WR	ER+NR	WR
Total technical efficiency	0.993	0.992	0.996	0.993
Return to scale	1.175	0.989	1.058	0.915
Pure technical efficiency	0.995	0.993	0.997	0.996
Scale efficiency	0.997	0.998	0.998	0.997

5 Conclusion

This paper employed the DEA method to measure the scale efficiency of airspace capacity. Meanwhile, this paper proposes new strategies to improve current airspace efficiency. The major findings from this study are summarized in the following:

First, the outcomes of the hourly scale efficiency for the airspace capacity in Taipei terminal area show that the average efficiency of east air sector is better than those of the north and west sectors. These outcomes can identify those hourly air sectors that are not scale efficiency and propose advance strategies or tactics of airspace capacity management to improve no efficiency hourly air sectors to be more efficient.

Second, the after recombination outcomes of hourly efficiency is better than before recombination. Therefore, the recombined air sector strategies can increase scale efficiency of airspace capacity.

Third, these hourly traffic patterns in each air sector can explore the relation between air sector characteristics and air traffic to predict the threshold of air sector capacity at a different time of a day.

Finally, this model can be employed to study airspace sector planning strategies, and can be used as references and tools to compare airspace efficiency differences between air routes and terminals.

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