THE EVALUATION OF AIRCRAFT OPERATIONS AT AIRPORTS HAVING DIFFERENT NUMBERS AND CONFIGURATIONS OF RUNWAYS

Özlem ŞAHİN[*]

Anadolu University, Faculty of
Aeronautics and Space Sciences
Eskişehir/Turkey
osahin5@anadolu.edu.tr

Öznur USANMAZ

Anadolu University, Faculty of
Aeronautics and Space Sciences
Eskişehir/Turkey
ousanmaz@anadolu.edu.tr

ABSTRACT

One of the important parts of the air transportation system is the airport which needs to increase its capacity due to a growth in air traffic demand. Many factors influence the capacity of an airport airside, and some are more significant than others, such as the numbers and configurations of runways. At first, constructing new runways appears to be a solution, but there is little possibility of expanding existing or adding new runways to many of Europe's most congested airports. As a result, service providers suggest increasing the capacity of airfields using existing runway components more efficiently. In this study, 388 European Airports are analyzed in terms of the number of aircraft operations, and a correlation analysis between the number of runways and operations is conducted. Furthermore, in order to predict the number of traffic operations with using the configuration and number of runways, multiple linear regression test is applied and a model is developed.

Keywords: *Airports, Runways, Capacity, Aircraft Operations, Correlation, Regression.*

FARKLI PİST SAYISINA VE KONFİGÜRASYONUNA SAHİP HAVAALANLARINDA UÇAK OPERASYONLARININ DEĞERLENDİRİLMESİ

ÖZET

Artan hava trafik talebi, hava ulaştırma sisteminin önemli bir parçası olan havaalanlarında kapasite arttırımı ihtiyacını ortaya çıkarmaktadır. Havaalanı hava tarafı kapasitesini etkileyen birçok faktör bulunmaktadır. Pist konfigürasyonu ve pist sayısı bu faktörlerin en önemlileri arasında yer almaktadır. Ilk bakışta, kapasite problemlerini çözmede yeni pistlerin eklenmesi çözüm gibi görünse de, Avrupadaki birçok yoğun havaalanında yeni bir pist eklenmesi ya da mevcut olanın genişletilmesi olasılığı çok düşüktür. Sonuç olarak, hizmet sağlayıcılar hava tarafı kapasitesinin arttırılmasında mevcut pist elemanlarının daha verimli şekilde kullanılmasını önermektedir. Bu çalışmada, Avrupa'daki 388 havaalanı, trafik operasyon sayısı açısından analiz edilerek, mevcut pist sayıları ile trafik operasyon sayısı arasındaki ilişki incelenmiştir. Bununla birlikte, pist konfigürasyonu ve pist sayısı ile trafik operasyon sayısı tahmini için çoklu lineer regresyon testi kullanılarak bir model geliştirilmiştir.

Anahtar Kelimeler: *Havaalanları, Pistler, Kapasite, Uçak Operasyonları, Korelasyon, Regresyon.*

---

[*] Corresponding Author

1. INTRODUCTION

There is a need to increase the capacity of airports, because of the growth of air traffic demand. One method to increase airport airside capacity is to improve the capacity of runways. An appropriate method to increase the runway capacity, which is a significant component of airside, is to add new runways or to change the configuration of runways in order to provide optimum usage. However, new runways, along with associated protection zones, noise buffer space, and such like, typically require acquisition of a large amount of additional land area. Equally important, they have significant environmental and other external impacts that necessitate long and complicated review-and-approval processes with uncertain outcomes [1]. Therefore, service providers suggest increasing the capacity by using existing runway system more efficiently.

Astholz et al. (1970) consider aircraft movements on the runway and in the final approach and departure volumes of the terminal area. To increase the capacity of runways, factors affecting runway capacity were analyzed. In this study, the capacity of a single runway could be increased in the short term by approximately 40 percent without changes in current separation standards. Moreover, in the longer term, it was anticipated that single runway capacity could be more than doubled with the introduction of improved guidance, flight control, air traffic control automation, and surveillance [2].

For Praha Ruzyne Airport, the annual rate of traffic growth was analyzed by The European Organization For the Safety of Air Navigation (EUROCONTROL). Adding a new rapid exit taxiway(s) is proposed in order to enhance the airport airside capacity. By this method, a reduction in the runway occupancy time for arrival and departure traffic is the aim [3].

In another EUROCONTROL study, capacity constraints for selected airports were analyzed and extra capacity for demand rate was researched. Finally, it has been found that wake vortex separations are a critical factor in determining runway capacity [4].

Audenaerd et al. (2009) analyzed a new wake turbulence procedure which has recently been approved for use at several airports allowing arrivals at these airports to reduce separation between aircraft on parallel approaches, in weather below visual approach minima, using a parallel dependent stagger arrival operation. This procedure, documented in JO 7110.308, allows aircraft to arrive in staggered pairs, with Large and Small wake category aircraft in the lead. It has been found that using this procedure, approximately half of the capacity normally lost due to deteriorating weather could be regained [5].

The study for airside of Charles de Gaulle airport aims to estimate its potential expansion in the future in view of traffic increase. The runway system and traffic were analyzed and, in the end, the total capacity was computed. Furthermore, a comparison of the capacity of similar airports - Los Angeles International Airport and Atlanta International Airport-was presented [6].

Levy et al. (2004) studied arrival rates at Memphis International Airport (MEM). This research describes the statistics of landing speeds and inter-arrival distances between successive arrivals at MEM during periods of sustained, heavy arrival rate. The percentages of aircraft in wake vortex weight categories, grouped by runway and meteorological class, are defined. These data and landing speed and inter-arrival distance spacing are used to estimate single runway arrival rates for various fleet mixtures and modeling assumptions. An equation was provided to estimate the average hourly arrival rate to a single runway as a function of maximum inter-arrival time between successive arrivals [7].

For Boston Logan Airport, annual Capacity Coverage Chart (CCC), showing how much capacity is available for a particular percentage of time, was prepared by analyzing historical statistics regarding frequency with possible combinations of visibility, ceiling and wind conditions at Boston Logan during the course of a year and identifying the runway configuration providing the highest capacity for each set of weather conditions. It summarizes the supply of airside capacity. Finally, it can be seen that depending on the number of runways and the airport's geometric configuration, total airside capacity of major commercial airports ranges from 25 per hour to 200+ per hour [8, 1].

Bazargan et al. (2002) studied a method to evaluate runway layouts using simulation, to aid in the airport planning and decision - making processes. For Philadelphia International Airport (PHL), different runway layouts were analyzed to increase the capacity of runways and, also, a TAAM (Total Airspace and Airport Modeller) was used to simulate each proposed alternative given its capabilities for modeling at a very high level of detail and closely representing reality in terms of applicable separation standards and air traffic control procedures [9].

Hunter (2010) studied about the airport capacity forecast which was based on four models. The models estimate the airport meteorological conditions, airport configuration, current airport capacity and future airport capacity. They focused a reduction on airport capacity due to weather. An overall airport capacity model, which could be used in several ways, has been developed [10].

Janic (2007) modeled a heuristic algorithm, based on linear and integer programming, for the allocation of runway capacity in order to minimize the cost of arrival and departure aircraft delays. The new algorithm is simple but is a suitable alternative to the already available optimization methods. Traffic scenarios were prepared using the algorithm and applied at three busy US airports. The results show very good performance of the proposed heuristic algorithm in the allocation of airport runway capacity [11].

Why peak runway pricing is not working to solve airside airport congestion was examined by Schank (2005). New York, Boston and London, where airports attempted to apply peak runway pricing, were analyzed. It was found that there may be some institutional barriers to peak pricing theory that prevent effective implementation. The spontaneous problem is that transportation policy is determined by governments and not by the free market. Peak pricing is an attempt to insert an element of the free market into a government-regulated market [12].

Urbatzka and Wilken (1997) studied the estimation of runway capacities of German airports. First, capacity and demand concepts were defined and approaches to estimating runway capacity (Empirical approaches, Queuing models, Analytical approaches, Simulation models) were also explained. Second, functions of take-off, landing and mixed mode runway capacity were researched. Finally, the results indicate that the hourly movement rate was mainly determined by the sequence pattern and the size and mix of aircraft in the landing and take-off processes [13].

Weld et al. (2010) researched the Runway Configuration Management (RCM) problem which shows what combinations of runways are in use and to what capacity. RCM is formulated as a Mixed Integer Linear Program (MILP) to determine a schedule of runway configuration changes to maximize efficiency, given forecasted available configurations and demand. The Marginally Decreasing Transition Capacities (MDTCs) formulation is also introduced. Both the base model and MDTCs model are used in parallel. The MDTC solution is preferred because it presents real world conditions more accurately [14].

In this study; for 388 European airports, one of the important and fundamental factors for determining runway capacity, that is the number and configuration of runways, will be analyzed and what correlation exists between these factors and annual aircraft movements will be researched. Also, multiple linear regression test will be conducted and regression model will be generated.

2. AIRPORT CAPACITY

The airport system consists of two major components, the airside and the landside. The airside includes all areas where aircraft may take off, land, taxi, or park, including runways, taxiways and aprons and all areas providing aircraft service, such as fuel farms, deicing pads, maintenance hangars, and so forth. The other part, the landside, begins at that areas of an airport where passenger loading device at gates connect with passenger terminals or concourses, and proceeds through the passenger building, cargo facilities, and ground access system [15]. Components of the airport system for passenger and aircraft flow are presented in Figure 1.

Capacity, generally refers to the ability of an airport to handle a given volume of traffic (demand). It is a limit that cannot be exceeded without incurring an operational penalty. As demand for the use of an airport approaches this limit, lines of users awaiting service begin to develop, and they experience delay. The higher the demand in relation to capacity, the longer the lines and the greater the delay [16].
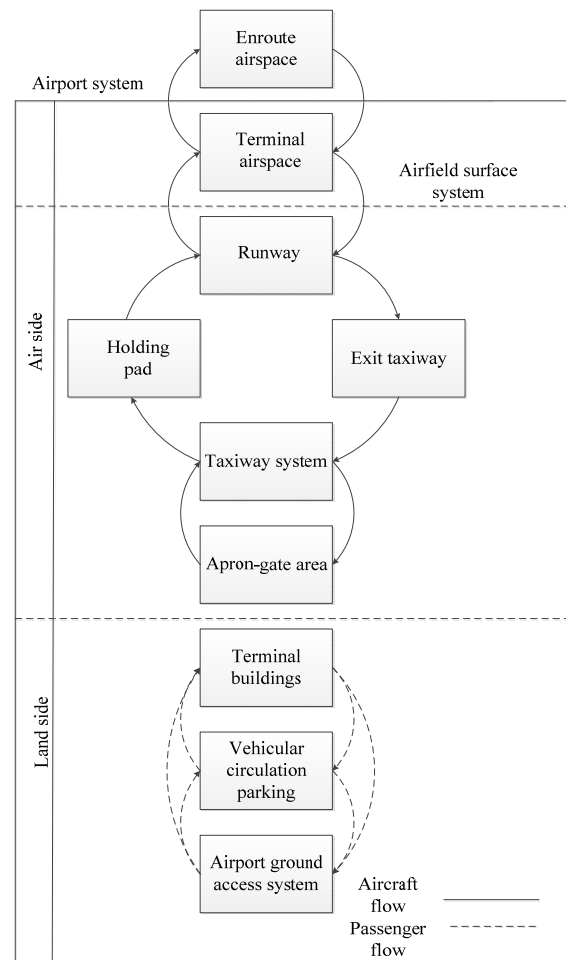

Figure 1. Components of the airport system for a large airport [17].

While calculating airside capacity, runway capacity is taken into consideration; in addition, to calculate the land side capacity, the functions of terminal building are taken into account.

2.1. The airfield capacity

The capacity of the airside, and especially of runway systems, determines the ultimate capacity of an airport. There are two commonly used definitions of airfield capacity: 'throughput' and 'practical capacity'. The maximum throughput capacity is the principal and most fundamental measure of the capacity of a runway system. It indicates the average number of movements that can be performed on the runway system in one hour in the presence of continuous demand, while adhering to all the separation requirements imposed by the air traffic management (ATM) system. Practical capacity is the number of operations (takeoffs and landings) that can be accommodated with no more than a given amount of delay, usually expressed in terms of maximum acceptable average delay. The practical capacity is equal to 80 or 90 percent of the maximum throughput capacity [16,1].
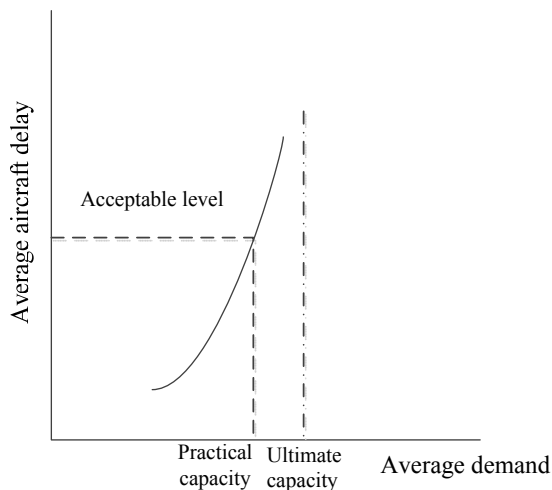

Figure 2. Relationship between Throughput and Practical capacity [17].

2.1.1.Runway capacity

The maximum throughput capacity of a runway system depends on many parameters and factors. The most important of these are the number and geometric layout of the runways, the ATM separation requirements, weather conditions (visibility, precipitation, wind direction and strength), mix of aircraft types, mix and sequencing of runway movements, type and location of runway exits, performance of the ATM system, and noise restrictions on operations. The runway system capacities that one encounters at major airports in various parts of the world span a wide range. In

developed countries, the capacity per runway at major airports ranges from 20 to 60+ movements per hour [1].

In this study, the capacity of runway which is based on the number and type of runways is taken account according to annual aircraft operations in 2006.

3. METHODOLOGY

The most obvious and probably the single most important factor influencing a runway system's capacity is the number of runways at the airport and their geometric layout. From a practical view, the surest way to achieve a 'quantum increase' in the capacity of an airport is by constructing a well-located (relative to the other existing runways) and well designed runway. Unfortunately, adding a new runway is a task that today ranges from very difficult to nearly impossible at most of the world's busiest and most congested airports [1]. Therefore, in this study, the air traffic movements of 388 European airports, based on the Airport Council International (ACI) database 2006 have been researched with the aim of analyzing the number and configuration of existing runways and investigating the correlation between these parameters and the number of annual aircraft operations.

One of the major factors determining the airport capacity is the number of runways. The correlation between traffic movements and number of runways in 388 European airports are conducted using the Statistical Package for the Social Sciences (SPSS) 10.0.

Besides the number of runways, another important factor influencing the capacity of an airport is runway configuration. There are four different types of runway configuration: single runways, parallel runways, crossing runways and converging runways [18]. Runway capacity varies according to the location of runways beside each other.

In this study, also, number and configuration of runways for predicting the number of aircraft operations are whether significant factors or not is researched. For this purpose by using SPSS 10.0 a multiple linear regression test is conducted.

A single runway is the simplest runway configuration [17]. In IFR conditions the capacity ranges from 50 to 59 operations per hour [19].

The capacities of parallel runway systems depend a great deal on the number of runways and on the spacing between them. Two and four parallel runways are common, but today some airports have three sets of parallel runways. The spacing between parallel runways varies widely. The spacing is classified as

close, intermediate and far, depending on the centerline separation between two parallel runways [17]. In IFR conditions, the hourly capacity of closely parallel runways ranges from 56 to 60 operations, for a pair of intermediate parallel runways from 62 to 75 operations, and for a pair of far parallel runways from 99 to 119 operations [19].

Two or more runways, where the magnetic alignment will have crossing flight paths and where the actual runway surfaces overlap, is referred to as 'crossing runways or intersecting runways' [18]. Intersecting runways are necessary when relatively strong winds come from more than one direction, resulting in excessive crosswinds when only one runway is provided. When the winds are strong, only one runway of a pair of intersecting runways can be used, reducing the capacity of the airfield substantially. If the winds are relatively light, both runways can be used simultaneously. The capacity of two intersecting runways depends a great deal on the location of the intersection (i.e., midway or near the ends). The farther the intersection is from the take off end of the runway and the landing threshold, the lower the capacity. In this case, in IFR conditions, the capacity ranges from 40 to 60 operations per hour. The highest capacity is achieved when the intersection is close to the take off and landing threshold. The capacity ranges from 60 to 70 operations per hour in IFR conditions [17]. According to the ICAO Doc 9184 'Airport Planning Manual', in IFR conditions the hourly capacity of intersecting runways ranges from 56 to 60 operations.

Converging runways are two or more runways where the magnetic alignment will have crossing flight paths within the surface area and where the runway surfaces do not overlap [18]. This configuration is a part of open-v runways. Like intersecting runways, open-v runways revert to a single runway when winds are strong from one direction. When the winds are light, both runways may be used simultaneously [17]. When the operations are away from the V, referred to as diverging operations, the hourly capacity ranges from 56 to 60 operations. When the operations are toward the V, referred to as converging operations, the hourly capacity ranges from 56 to 60 operations [17, 19].

In this study, annual number of operations for year 2006, the number and configuration of runways are analyzed for 388 European airports individually. While analyzing the configuration of runways, the weather conditions are not taken into account. In order to find how much the coefficients effect the number of aircraft operations, a multiple linear regression test is conducted, and a regression model is obtained. Results will be discussed in the following chapter.

4. RESULTS AND DISCUSSION

While analyzing the correlation between the numbers of operations based on ACI and the number of runways, SPSS program is used. In the result of correlation analysis, it is found that there is a positive, moderate correlation between the number of annual aircraft operations and the number of runways (p<.01 r=0,518) (Table 1).

Table 1. SPSS 10.0 correlation analysis results.

			RWY	Operation
Spearman's rho	RWY	Correlation Coefficient	1,000	,518**
		Sig. (2-tailed)	.	,000
		N	388	388
	Operation	Correlation Coefficient	,518**	1,000
		Sig. (2-tailed)	,000	.
		N	388	388

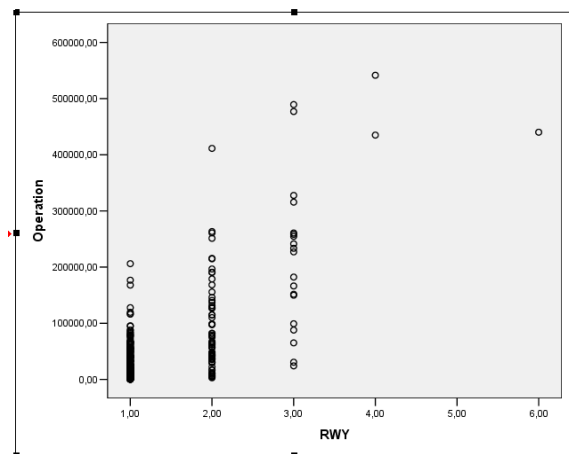**. Correlation is significant at the 0.01 level (2-tailed).

Figure 3. Relationship between the number of aircraft operations and number of runways.

The one of the major factors determining airport airside capacity is the number of runways. The relationship between traffic movements and the number of runways at 388 European airports are shown in Figure 3.

In addition, in this study, the configuration of runways is analyzed for 388 European airports. It can be seen that 297 (77%) airports have a single runway, 43 airports (11%) have crossing or converging and 33 airports (9%) have only parallel runways. Eleven airports (3%) are seen to have parallel and crossing or converging runways (Figure 4).

In terms of the numbers of annual aircraft operations for 2006, Europe's the most congested airports with different runway configurations are shown below in Figure 5, 6 and 7.
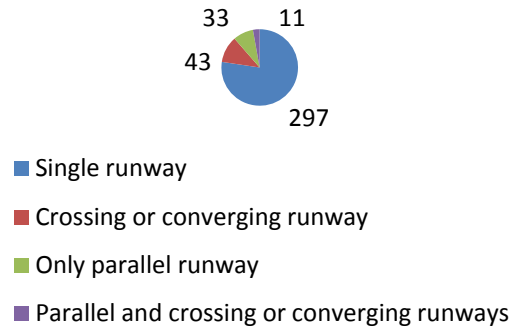
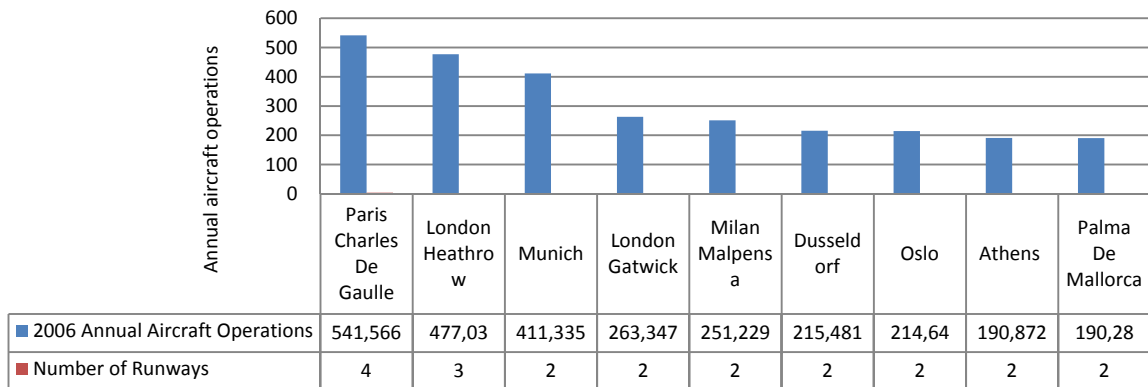**Figure 4.** The distribution chart of airports according to runway configuration.

	Paris Charles De Gaulle	London Heathrow	Munich	London Gatwick	Milan Malpensa	Dusseldorf	Oslo	Athens	Palma De Mallorca
■ 2006 Annual Aircraft Operations	541,566	477,03	411,335	263,347	251,229	215,481	214,64	190,872	190,28
■ Number of Runways	4	3	2	2	2	2	2	2	2

Figure 5. Europe's first ten airports with parallel runways in terms of annual aircraft operations for 2006 [20].

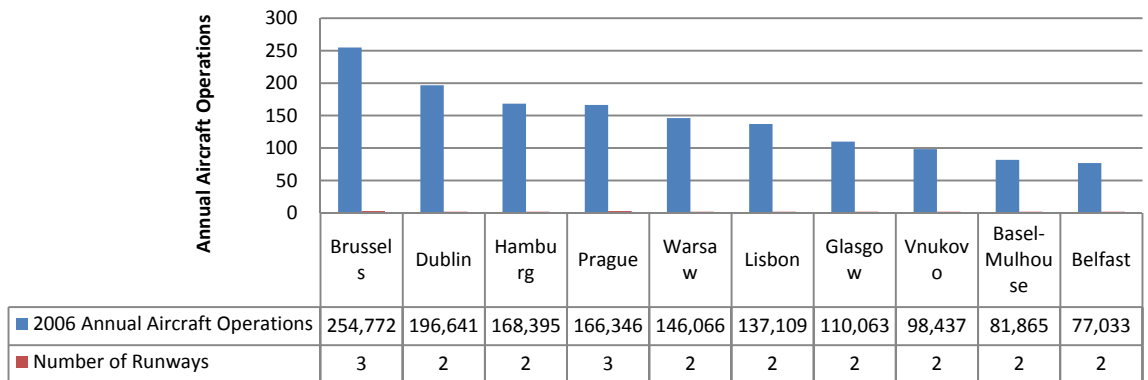|	Brussels	Dublin	Hamburg	Prague	Warsaw	Lisbon	Glasgow	Vnukovo	Basel-Mulhouse	Belfast
■ 2006 Annual Aircraft Operations	254,772	196,641	168,395	166,346	146,066	137,109	110,063	98,437	81,865	77,033
■ Number of Runways	3	2	2	3	2	2	2	2	2	2

Figure 6. Europe's first ten airports with crossing runways in terms of annual aircraft operations for 2006 [20].

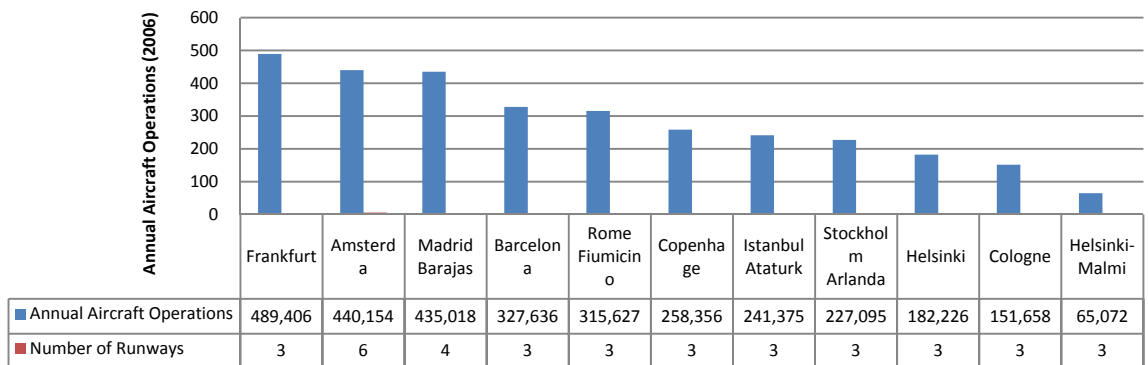|	Frankfurt	Amsterda	Madrid Barajas	Barcelona	Rome Fiumicino	Copenhage	Istanbul Ataturk	Stockholm Arlanda	Helsinki	Cologne	Helsinki-Malmi
■ Annual Aircraft Operations	489,406	440,154	435,018	327,636	315,627	258,356	241,375	227,095	182,226	151,658	65,072
■ Number of Runways	3	6	4	3	3	3	3	3	3	3	3

Figure 7. Europe's airports with parallel & crossing & converging runways in terms of annual aircraft operations for 2006 [20].

According to different runway configurations, as it presented in Figure 5, 6 and 7, the first ten airports are chosen and total annual aircraft operations are compared. The results below are obtained (Figure 8).
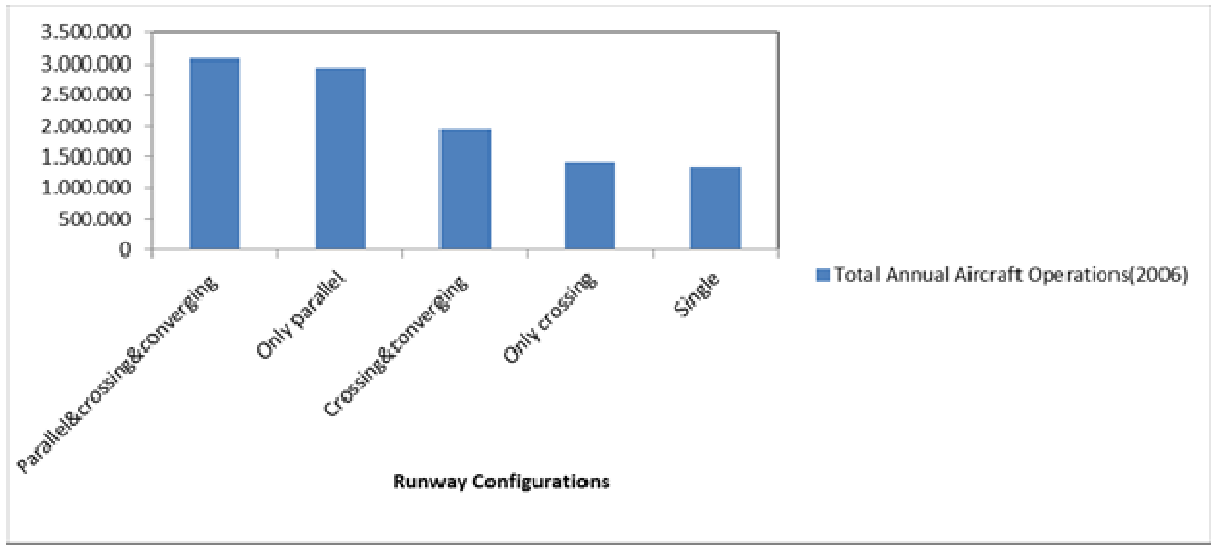

Figure 8. The ten most congested airports' annual total aircraft operations on different runway configurations.

The relationship between the number of runways at European airports and the number of aircraft operations is positive and moderate. Therefore, by adding a new runway, a linear increase cannot be expected in the number of operations, namely the amount of service provided. Analyzing European airports we can see that, London Stansted has a single runway and annual traffic of 206,000, however, Dusseldorf Airport with two parallel runways has 215,481 operations annually. From this result, a moderate correlation of the number of runways and the amount of traffic is confirmed. Besides the number of runways, runway configuration is one of the important factors for increasing the runway capacity.

In this study, for selected 10 airports with different runway configuration which are shown in Figures 5, 6, 7 and 8, the results below are obtained:

- On parallel runways, the number of operation is more than that on crossing runways. The capacities of parallel runway systems depend a great deal on the number of runways and parallel runways allowing simultaneous arrivals and departures, so the amount of traffic which is served, is more than for other runway configurations (Figure 8).
- Crossing runways do not always allow simultaneous arrival and departure; therefore, they are used like single runways. The number of aircraft on only crossing runways and on only single runways are closely match (Figure 8).

- Besides the crossing/converging runways, in the case of existing parallel runways, a 57% increase in the amount of traffic was observed.

Secondly, a regression model is established and the significance of the model is researched. The number of aircraft operations is defined as a dependent variable and the number and configuration of runways are defined as independent variables. As it seen the number of runway is a quantitative variable and the configuration runway is a qualitative variable and it has some kinds of categories (m) as single, parallel, crossing etc. runways. Therefore, dummy variables (m-1) are defined according to '1' or '0'. Parallel & crossing & converging runways are considered as a constant.

Y_t = operation number
X_t = runway number
u_t = error
D_1 = 1 single runway, $\quad\quad$ D_1= 0 not single runway
D_2 = 1 parallel runway, $\quad\quad$ D_2 = 0 not parallel runway
D_3 = 1 crossing runway, $\quad\quad$ D_3 = 0 not crossing runway
D_4 = 1 converging runway, $\quad\quad$ D_4= 0 not converging runway
D_5 = 1 parallel & converging, $\quad\quad$ D_5 = 0 not parallel &converging runway
D_6 = 1 crossing & converging, $\quad\quad$ D_6 = 0 not crossing &converging runway

D_7 = 1 parallel & crossing, D_7 = 0 not parallel &crossing runway

Regression model:

$Y_t = \alpha_1 + \alpha_2 D_1 + \alpha_3 D_2 + \alpha_4 D_3 + \alpha_5 D_4 + \alpha_6 D_5 + \alpha_7 D6 + \alpha_8 D7 + \beta X_t + u_t$

Expected values are shown below.

$E (Y_t, X_t, D_1 = 0, D_2 = 0, D_3 = 0, D_4 = 0, D_5 = 0, D_6 = 0, D_7 = 0)$

$E (Y_t, X_t, D_1 = 1, D_2 = 0, D_3 = 0, D_4 = 0, D_5 = 0, D_6 = 0, D_7 = 0)$

$E (Y_t, X_t, D_1 = 0, D_2 = 1, D_3 = 0, D_4 = 0, D_5 = 0, D_6 = 0, D_7 = 0)$

$E (Y_t, X_t, D_1 = 0, D_2 = 0, D_3 = 1, D_4 = 0, D_5 = 0, D_6 = 0, D_7 = 0)$

$E (Y_t, X_t, D_1 = 0, D_2 = 0, D_3 = 0, D_4 = 1, D_5 = 0, D_6 = 0, D_7 = 0)$

$E (Y_t, X_t, D_1 = 0, D_2 = 0, D_3 = 0, D_4 = 0, D_5 = 1, D_6 = 0, D_7 = 0)$

$E (Y_t, X_t, D_1 = 0, D_2 = 0, D_3 = 0, D_4 = 0, D_5 = 0, D_6 = 1, D_7 = 0)$

$E (Y_t, X_t, D_1 = 0, D_2 = 0, D_3 = 0, D_4 = 0, D_5 = 0, D_6 = 0, D_7 = 1)$

By using SPSS 10.0, a multiple linear regression test is done. This study aims to predict the number of operation according to number and configuration of runways. According to the regression test, the results of variance analysis (Anova), model summary and coefficients are shown in Table 2, 3 and 4.

Table 2. Anova results.

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1E+012	8	1,792E+011	77,450	,000^a
	Residual	9E+011	379	2314375078		
	Total	2E+012	387			

a. Predictors: (Constant), D7, D6, D5, D4, D3, D2, RWY, D1

b. Dependent Variable: Operation

Table 3. Model summary.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,788^a	,620	,612	48107,95234

a. Predictors: (Constant), D7, D6, D5, D4, D3, D2, RWY, D1

Table 4. Coefficients.

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.	Correlations Zero-order	Partial	Part	Collinearity Statistics Tolerance	VIF
1	(Constant)	-151266	43887,915		-3,447	,001					
	RWY	102988,5	10625,768	,833	9,692	,000	,721	,446	,307	,135	7,382
	D1	73723,394	35070,199	,398	2,102	,036	-,558	,107	,067	,028	35,867
	D2	73141,042	27569,739	,264	2,653	,008	,384	,135	,084	,101	9,916
	D3	2192,547	28109,373	,008	,078	,938	,067	,004	,002	,097	10,308
	D4	7081,282	31588,211	,013	,224	,823	,048	,012	,007	,296	3,378
	D5	163406,4	30721,575	,239	5,319	,000	,433	,264	,168	,497	2,013
	D6	89421,928	40751,798	,083	2,194	,029	,185	,112	,069	,700	1,428
	D7	169935,9	53083,864	,112	3,201	,001	,183	,162	,101	,823	1,214

a. Dependent Variable: Operation

The number and configuration of runway variables together have strong and significance relationship with the number of aircraft operations (R = 0.788, R^2 = 0.62, p< .01). These variables explain approximately 62% the total variance of the operation number (Table 3). Regression model been created is significant statistically according to the results of F test p<0.1 (Table 2).

According to standardized regression coefficient (ß), effects of the independent variables on the number of operation could be ordered in terms of the importance such as; runway number (RWY), single runway (D1),

parallel runways (D2), parallel & converging runways (D5), parallel & crossing runways (D7), crossing & converging runways (D6), converging runways (D4) and crossing runways (D3). When the results of the t test is analyzed, it is seen that the coefficients of the crossing and converging runways ($p > .05$) are not significant statistically. Other coefficients are the significant ($p < .05$) on the dependent variable. Also constant refers to parallel & crossing & converging runways. In terms of the coefficients a regression model which is obtained below.

$$Y_t = -151266 + 73723,394 \ D_1 + 73141,04 \ D_2 + 2192,547 \ D_3 + 7081,282 \ D_4 + 163406,42 \ D_5 + 89421,928 \ D_6 + 169935,93 \ D_7 + 102988,55 \ X_t$$

It can be seen that coefficients of single runways and parallel runways are close to each other but the number of runways also should be evaluated. Except crossing and converging runways, all other coefficients of the variables are statistically significant. It is important to point out that individually crossing or converging runway configurations are not significant, but in cases of existing parallel runways with them, they become significant.

5. CONCLUSIONS

The major factors determining the airport airside capacity are number and configuration of runways. In this study, the aim is to analyze the relationship between the existing number and configuration of runways and the number of operations in European airports; thus, a correlation analysis for measuring the relationship between the number of runways at European airports and aircraft operations is conducted. It is established that the relationship is positive and moderate. Furthermore, different runway configurations affect the number of operations in different ways. The results show that airports with only have parallel runways operate more service than other runway configurations. Comparing ten most congested airports with different configuration, it can be seen that airports with only parallel runways manage annual aircraft operations from between 541,566 to 190,280, but airports with only crossing runways manage the number of aircraft operations from 254,772 to 77,033. The number of operation at four airports is less than 100,000. In cases having the all types of runways, the number of aircraft operations range from 440,154 to 65,072. It is not more than only parallel runways; at only one airport is the number of aircraft operations less than 100,000. It is clear that airports with parallel runways have more aircraft operations than crossing runways. Moreover, at an airport with crossing/converging runways, also in cases of existing parallel runways, an increase in the number of aircraft operations is observed. It is also proved by the regression model.

In addition, the relationship between the numbers & configurations of runways and the numbers of operations is explained by creating regression model. This model is significant in term of the results of F test. Moreover, the coefficients are evaluated according to t test and finally except the coefficients of crossing and converging runways, all others are found significant statistically.

In order to increase the airport capacity, the construction of new runways and runway extensions at existing airports has offered potential, but these options are difficult because of surrounding community development, environmental concerns, shortage of available adjacent property and funding required, lack of public support, rival commercial and residential interests, and other competing requirements [16]. Because of this, in this study, it is shown that using existing runways with maximum efficiency is preferable. If there is the possibility of adding new runways, parallel runways providing simultaneous operations should be preferred. Moreover, from the results of regression model, crossing/converging runways are not significant ($p > .01$), except in cases of existing parallel runways. So that, besides the parallel runways, parallel & converging or parallel & crossing runways could also be preferable.

6. REFERENCES

[1]   Neufville, R., Odoni A. 2003. Airport Systems, Planning, Design, and Management. New York, McGraw Hill Inc., New York.

[2]   Astholz, P. T., Sheftel D., Harris R., 1970. Increasing Runway Capacity. Proceeding of the IEEE, 58(3), 300.

[3]   Zeinert, P., Hlousek P., Kraus P., Duka T., 2004. Airport Capacity Enhancement. Praha Ruzyne Airport, Eurocontrol Leaflet, Available from:

http://www.eurocontrol.int/airports/gallery/content/public/pdf/Prague%20leaflet%20Phase%201.pdf (Accessed 11 October 2011).

[4]   Galpin, D., Pugh, C., Turp, D., 2005. European Wake Vorteks Mitigation Benefits Study, Work Package 1 Deliverable : Identification of WV Constrained Airports, Eurocontrol.

[5]   Audenaerd, L., Domino, D., Lang, S., Lunsford, C., Smith, A., Tittsworth, J., 2009. Increasing Airport Arrival Capacity in NextGen with Wake Turbulence Avoidance. ICNS Conference 13-15 May.

[6]   Leroyer, P., 2004. Airside Study of Charles de Gaulle Airport, Airside Organization Traffic Growth and Risks of Congestion. Massachusetts Institute of Technology, USA.

[7] Levy, J., Legge, J., Romano, M., 2004. Opportunities For Improvements In Simple Models For Estimating Runway Capacity. IEEE.

[8] Odoni, A. R. 2004. Airport Systems Course. Massachusetts Institute of Technology, USA. Available from:

http://ardent.mit.edu/airports/ASP_current_lectures/ASP%2004/Airfield_Capacity_04_bw.pdf (Accessed 20 September 2011).

[9] Bazargan, M., Fleming, K., Subramanian, P., 2002. A Simulation Study To Investigate Runway Capacity Using TAAM. 2002 Winter Simulation Conference (WSC'02) – Vol. 2

San Diego, CA, USA.

[10] Hunter, G., 2010. Probablilistic Forecasting Of Airport Capacity. 29th Digital Avionics Systems Conference October 3-7.

[11] Janic, M., 2007. A Heuristic Algorithm for the Allocation of Airport Runway System Capacity. Transportation Planning And Technology, 30(5), 501-520.

[12] Schank, L., J., 2005. Solving Airside Congestion: Why Peak Runway Pricing is Not Working. Journal of Air Transport Management 11, 417-425.

[13] Urbatzka, E., Wilken, D., 1997. Estimating Runway Capacities of German Airports. Transportation Planning and Technology, 20, 103 - 129.

[14] Weld, C., Duarte, M., Kincaid, R., 2010. A Runway Configuration Management Model With Marginally Decreasing Transition Capacities. Advances in Operations Research Volume 2010, Article ID 436765.

[15] Dempsey, P. S., 1999. Airport Planning&Development Handbook. New York, McGraw Hill Inc., A Global Survey.

[16] Wells, A.T., 2000. Airport Planning and Management. New York, McGraw Hill Inc., Fourth edition.

[17] Horonjeff, R., McKelvey F. X., 1993. Planning&Design of Airports. Boston, McGraw Hill Inc., Fourth edition.

[18] FAA Order 7210.57- CD Release January 31, 1998.

[19] International Civil Aviation Organization (ICAO) DOC 9184 Airport Planning Manual, Part I, Master Planning. Second edition, 1987.

[20] Airport Council International (ACI), (2006). Airport Database.

VITAE

Öğr. Gör. Dr. Özlem ŞAHİN
She was born in Eskişehir, Turkey, in 1980. She received her B.S. degree in The School of Civil Aviation, Department of Air Traffic Control from Anadolu University in 2003. She began as a research assistant at The School of Civil Aviation, Anadolu University in 2003. She received her M.S. degree from Graduate School of Science at Anadolu University in 2006. She received her Ph.D. degree from Graduate School of Science, Department of Civil Aviation at Anadolu University in 2011. She has been working at Anadolu University, Aeronautical and Space Science Faculty, Department of Air Traffic Control as an instructor doctor. Her research interest includes flight procedures, navigation and aircraft operations.

Yard. Doç. Dr. Öznur USANMAZ
She was born in Eskişehir, Turkey, in 1968. She received her B.S. degree in Electrical and Electronics Engineering from Anadolu University in 1990. She received her M.S. degree from Ecole Nationale de l'Aviation Civile (ENAC) in France. , She began as a research assistant at The School of Civil Aviation, Anadolu University in 1992. She received her Ph.D. degree from Graduate School of Science, Department of Civil Aviation at Anadolu University in 1999. She has been working at Anadolu University, Aeronautical and Space Science Faculty, Department of Air Traffic Control as an assistant professor doctor. Her research interest includes flight procedures, aircraft operations and air traffic management.