

AIRPORT NEEDS ASSESSMENT FOR ISTANBUL

by

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## **ABSTRACT**

### **AIRPORT NEEDS ASSESSMENT FOR ISTANBUL**

Since the airports are the gateways of metropolitans and countries to the world, they play important roles in the development of them. Istanbul, the business and tourism centre of Turkey, has two airports, namely Atatürk International Airport and Sabiha Gökçen International Airport. The sufficiency of these airports in meeting the present and future needs should be assessed and strategies for alleviating the potential problems should be presented in order not to hinder the economic and social development of not only the city but also the country. The main goal of this study was to analyze the capacities of Istanbul airports, to compare with the forecasted demand for the next 15 years, so as to evaluate their sufficiency in terms of satisfying the future demand and finally recommending solutions to alleviate the identified problems. Within this framework, first the airport capacities of both airports are determined. The key element of an airport capacity has been identified as runway capacity. Following the calculation of the runway capacities for both airports, the aircraft movement demand was forecasted for Istanbul for the next 15 years. The analysis of capacity of these airports and the estimated demand pointed out the insufficiency of current airports in meeting future demand. After discussing various alternatives and actions for enhancing the capacities of airports, the need for a new airport was concluded. An analysis for finding the most convenient location for the new airport was presented. Finally, the other systems of airports that may affect the airport capacity but not assessed in this study were summarized and further research areas were recommended.

## ÖZET

### İSTANBUL HAVALİMANI İHTİYAÇ ANALİZİ

Havalimanları şehirlerin ve ülkelerin dünyaya açılan kapıları oldukları için, ülkelerin gelişim süreçlerinde önemli bir rol oynarlar. Türkiye'nin iş ve turizm merkezi olan İstanbul'da Atatürk Uluslararası Havalimanı ve Sabiha Gökçen Uluslararası Havalimanı olmak üzere iki adet havalimanı mevcuttur. Şehrin ve ülkenin ekonomik ve sosyal gelişim sürecini engellemek için bu havalimanlarının şimdiki ve gelecekteki yeterlilikleri önceden analiz edilmeli ve belirlenen problemlerin çözümleri için stratejiler geliştirilmelidir. Bu çalışmanın ana amacı İstanbul'daki mevcut havalimanlarının kapasitelerini tespit edip, önümüzdeki 15 yılda doğabilecek ihtiyaca ile kıyaslayıp, yeterliliğini sınamak ve bulunan sorunlar için çözümler önermektir. Bu kapsamda öncelikle havalimanlarının kapasiteleri hesaplanmıştır. Havalimanı kapasitesini belirleyen en önemli sistemin pist kapasitesi olduğu tespit edilmiştir. Her iki havalimanı için pist kapasiteleri hesaplandıktan sonra, pistler tarafından karşılanacak uçak hareketleri önümüzdeki 15 yıl için tahmin edilmiştir. Bu havalimanları için yapılan arz ve talep analizi mevcut havalimanlarındaki yetersizlik belirlenmiş, İstanbul'un yeni bir havalimanına ihtiyaç duyacağını ortaya çıkmıştır. Bunu takiben, mevcut havalimanlarının kapasitelerini artırmak için yapılabilecek alternatif çözümler ile yeni havalimanı için en uygun konum belirtilmiştir. Son olarak, bu çalışmada inceleme konusu olmayan havalimanını kapasitesini etkileyebilecek diğer sistemler özetlenmiş ve gelecekte yapılabilecek araştırma konuları tavsiye edilmiştir.

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## LIST OF SYMBOLS / ABBREVIATIONS

$R^2$	Coefficient of determination
$Y_i$	Number of event occurring
$X_i$	The value of the Independent Variable
$e$	Error term
$\beta$	Regression coefficient
$t_{ij}$	Minimum time interval between successive movements
$P_{ij}$	Probability of a type $i$ aircraft followed by type $j$ aircraft
$r$	The length of the common approach path
$s_{ij}$	Separation minima between two successive type $i$ and $j$ aircraft
$v_i$	Speed of aircraft $i$ on final approach
$\mu$	Maximum throughput capacity
$o_i$	Runway occupancy time for type $i$ aircraft
$k$	Ratio of practical annual capacity to throughput annual capacity
$E[T_{ij}]$	Expected value if time interval between successive movements
ATM	Air Traffic Management
AVOSS	Aircraft Vortex Spacing System
BOT	Build Operate Transfer
DHMI	General Directorate of Civil Aviation
DLH	Railways Harbors Airports General Directorate
DPT	State Planning Organization
FAA	Federal Aviation Administration
GDP	Gross Domestic Product
HEAS	Airport Operation and Aviation Industries Co
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IMP	Istanbul Metropolitan Planning Center
ITU	Istanbul Technical University

LOS	Level of Service
MTOW	Maximum Certified Takeoff Weight
NASA	National Aeronautics and Space Administration
NLA	New Large Aircraft
NM	Nautical Mile
RET	Rapid Exit Taxiway
ROT	Runway Occupancy Time
RSS	Residual Sum of Squares
SPSS	Statistical Package for Social Sciences
SSR	Regression Sum of Squares
SST	Error Sum of Squares
TUIK	Turkish Statistical Institute
VFR	Visual Flight Rules

# 1. INTRODUCTION

## 1.1. Problem Definition

Istanbul has a significant role in both domestic and international air transportation due to not only its geopolitical, economical and social status as a business center, but also, because of its cultural characteristics, historical background and touristic potential. Istanbul is one of the oldest cities in the world and having the unique Bosphorus straight connecting the two continents, namely Asia and Europe. Istanbul has the 18 percent of the country's population and generates 22 percent of the Gross Domestic Product of Turkey (IMP, 2008). These figures are equal to the sum of 40 other cities in Turkey. Moreover, Istanbul accommodates 3.4 millions foreign tourists, 99 percent of which use air transportation (IMP, 2008). Therefore, Istanbul has a growing air traffic demand which should be handled to support its future development.

Atatürk International Airport and Sabiha Gökçen International Airport, located on the Europe and Asia respectively, are the two major airports serving the city. The locations of these airports are shown in Figure 1.1.



Figure 1.1. The Layout of Airports in Istanbul

The efficient movement of aircraft, passengers and cargo between airports is highly dependent on two key characteristics of an airport's operations: the demand by aircraft operators and passengers, and the capacity of the airport, both in airspace and local environment (Wells and Young, 2004). A major concern of airport planning and management is the adequacy of an airport's airfield, specifically in relation to the layout of the airport's runways, to handle the anticipated demand of aircraft operations. If air traffic demand exceeds airport or airspace capacity, delays will occur, increasing cost of operation to air carriers, inconvenience to passengers, and increased workload for the air traffic control system as well as airport employees and administrators. On the other hand, overestimated capacity results in worthless investment and operation expenses.

In the past, numerous studies have been performed to define demand-capacity relationship for Istanbul Airports. "Atatürk Airport Development Study (1997)" and "Sabiha Gökçen Airport Development Study (1997)" were prepared by Istanbul Technical University (ITU) upon request of Railways Harbors Airports General Directorate (DLH). Meanwhile General Directorate of Civil Aviation (DHMI) and DLH has utilized "Turkish Air Traffic General Study" (1999). ITU study was performed for a planning horizon till 2010. Therefore, we can compare the actual figures with the estimates. The comparison of both estimates and actual figures are illustrated in Table 1.1 in below:

Table 1.1. Comparison of Previous Estimate Studies with Actual Figures

#	DESCRIPTION	ACTUAL		ESTIMATE						
		2005	2009	2000	2001	2005	2006	2010	2011	2016
1	Total Aircraft Movement in Istanbul Airports ( <i>ITU study</i> )	233.750	344.413	210.105	-	275.017	-	383.399	-	-
2	Total Aircraft Movement in Ataturk Airport ( <i>DLH&amp;DHMI study</i> )	219.118	283.407	-	245.000	-	259.000	-	270.500	284.600

It was estimated that, in 2005 total aircraft movement would be 275,017, however, it turned out 233,750 movements. Thus, it can be stated that ITU study had overestimated the demand by 18 percent. Moreover, this study was limited to year 2010. On the other hand, DHMI and DLH study extends to 2016. However, this study only dealt with the airports which are managed by DHMI, hence, excluded Sabiha Gökçen Airport. In addition to that, when we compare the actual figures with the forecasted figure, it was seen that the study underestimated the demand. It was estimated that total aircraft movement would be

284,600 in Atatürk International Airport in year 2016; however in 2009 the total movement will be 283,407 according to estimate done with the actual data till November, 2009 (DHMI). In summary, there is no forecast study performed before which had resulted with reasonable estimates for airport demand.

A capacity analysis was done for Ataturk International Airport in ITU study. However, this study was conducted prior to construction of the parallel runway to RWY 18-36 which started operation at 2004. Therefore, the result of that study is not applicable for today's conditions.

## **1.2. Goals, Objective and Scope**

The main goal of this thesis is to analyze the capacity and to forecast the demand for the next 15 years in order to evaluate the sufficiency of airports in Istanbul. To serve this main goal, following objectives have been targeted:

- a thorough literature review on methods for performing airport capacity analysis and demand forecast of airports,
- calculation of capacities for Istanbul airports,
- demand forecasts of Istanbul airports,
- comparison of estimated demand and capacity,
- recommendation of short- and long-term remedies for identified problems,
- determination of topics of further research in the related areas.

## **1.3. Outline**

The next Chapter is a brief summary of some of the previous work on determination on airport capacity and demand forecast. In Chapter 3, the methodology used in this study, capacity determination method and the statistical background which is utilized in demand forecast are presented. Chapter 4 focuses on the determination of airport capacities in Istanbul. The regression analysis and demand forecast for design year is presented and the comparison with the capacity is carried out in Chapter 5. The final Chapter summarizes the research findings and conclusions and gives some recommendations for further research.

## 2. LITERATURE REVIEW

### 2.1. Airport Capacity

It is essential to realize at the outset that, from a long term perspective, airport capacity is a probabilistic quantity, i.e., a random variable, which can take on different values at different times, depending on circumstances involved such as weather conditions, aircraft fleet mix, pilot performance and so on. Thus, numbers cited for airport capacity, typically refer to “average number” or, more formally, “expected number” of movements that can be performed per unit time (de Neufville and Odoni, 2003).

Essentially, there are two commonly used definitions to describe airport capacity worldwide: maximum throughput capacity and practical capacity (Wells and Young, 2004). However, practical capacity is also identified in two other names; sustained capacity and declared capacity in Federal Aviation Administration (FAA). Maximum throughput capacity, which is also called saturation capacity, is defined as the ultimate rate at which aircraft operations may be handled in presence of continuous demand without regard to any small delays that might occur as a result of imperfections in operations or small random events that might occur. Maximum throughput capacity; for example, does not take into account the small probability that an aircraft will take longer than necessary to take off, or a runway must close for a very short period of time because of the presence of small debris. Maximum throughput capacity is truly the theoretical definition of capacity and is the basis for airport capacity planning.

Practical capacity is understood as the number of operations that may be accommodated over time with no more than a nominal amount of delay, usually expressed in terms of maximum acceptable average delay. Such minimal delays may be a result of two aircraft scheduled to operate at the same time, despite the fact that only one runway is available for use, or because an aircraft must wait a short time to allow ground vehicles to cross. Two measures of practical capacity are defined to evaluate the efficiency of airport operations. Practical hourly capacity (PHOCAP) and Practical annual capacity (PANCAP)

are defined as the number of operations that may be handled at an airport that results in not more than 4 minutes average delay during the busiest, known as the peak, 2-hour operating period, hourly and annually, respectively (de Neufville and Odoni, 2003).

The other two definitions for practical capacity are sustained capacity and declared capacity (de Neufville and Odoni, 2003). Sustained capacity is defined as the number of movements per hour that can be reasonably sustained over a period of several hours. "Reasonably sustained" refers primarily to the workload of air traffic management (ATM) system. Declared capacity is also based on the same general notion as sustained capacity and defined as the number of aircraft movements per hour that an airport can accommodate at a reasonable level of service (LOS). This reasonable level of service criteria will be explained in following sections in detail (Table 2.2.).

In conclusion, practical, sustained capacity and declared capacities are rather subjective measures of capacity that can be useful in some instances. The common characteristic of all three is that they define capacity indirectly, through explicit or implicit specification of an acceptable threshold of LOS or delay. They are also derivative measures of maximum throughput capacity and typically equal to 80 to 90 percent of the maximum throughput capacity (de Neufville and Odoni, 2003). Thus, one should firstly compute maximum throughput capacity in order to find the capacity of an airport.

Capacity should not be confused with demand. Capacity refers to physical capability of an airport and its components. It is a measure of supply and it is independent of both the magnitude and fluctuation of demand and amount of delay experienced by aircraft. Aircraft delays can be reduced by increasing capacity and by providing more uniform demand (i.e., via reducing the peaks in demand) (Ashford and Wright, 1992). These relationships are illustrated in Figure 2.1

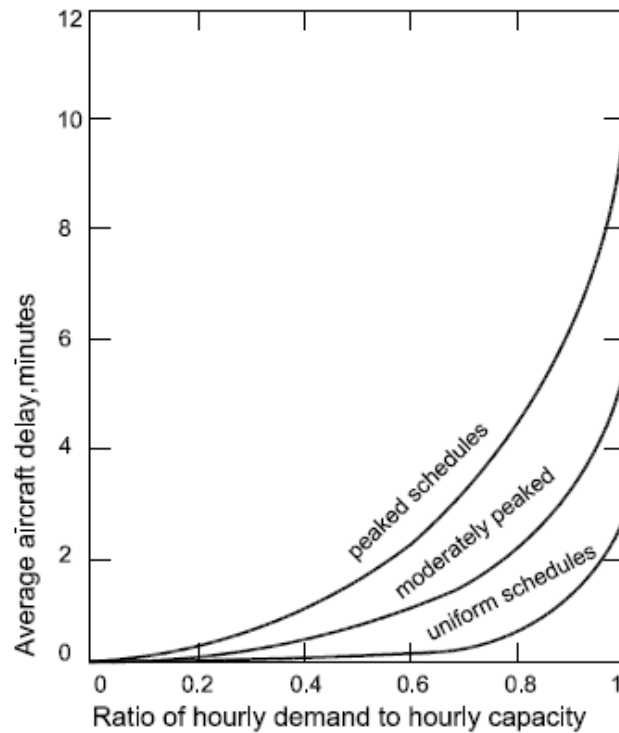


Figure 2.1. Relationship of demand capacity ratio-demand fluctuation to average delay (Ashford and Wright, 1992)

Bottlenecks and delays can result from inadequacies in any component of airport system: airside or landside. Therefore capacity analysis should be performed for each component (Ashford and Wright, 1992). These are explained in the succeeding two sections. Moreover, balancing these capacities is primarily required to avoid displacing a bottleneck to another critical facility.

### 2.1.1 Airside Capacity

There are four main elements of air side that affects the capacity (IATA, 2004):

- Runway
- Taxiway
- Apron
- Aircraft Stand

An overview of each element and their role in capacity of airport is briefly described in following paragraphs.

The runway system is a critical component to the overall system, and runway capacity ultimately determines a given airport's maximum capacity (IATA, 2004). Every effort should be made to ensure that other airport facilities are not limiting runway throughput and performance. Runway capacity is defined as the hourly rate of aircraft operations (departures, arrivals or both, as indicated) which can reasonably be expected to be accommodated by a runway or combination of runways, under specified local conditions. The capacity of a runway is not constant (de Neufville and Odoni, 2003). Capacity varies considerably based on a number of factors, including the utilization of runways, the type of aircraft operating, known as the fleet mix, the percentage of takeoff and landing operations being performed, and ambient climatic conditions. When a specific number is given for airfield capacity at an airport, it is usually an average number based on some assumed range of conditions.

The legal requirements of in-air separation in final approach phase and departure phase are the major constraints of runway capacity (Gerz *et al.*, 2002). A runway capacity is determined by rules of traffic flow and aircraft population (Blumstein, 1959). Rules of traffic flow require two successive aircraft to at least have a minimum between them, and only one aircraft can be on the runway at any time. Aircraft types and their mix determine aircraft population (Xie, 2005).

The current separation standards for terminal area are effective but are likely to be over protective (Gerz *et al.*, 2002). An over conservative separation rule will keep aircraft more separated than necessary to maintain safety, and it will waste precious time and resources. However, the reduction of separation under the pressure of traffic without a comprehensive and sound safety analysis could put aircraft and passengers in danger (Haynie, 2002). Research to date indicates substantial capacity improvements can be achieved by reducing separation constraints. O'Connor (2001) estimates the maximum Instrument Flight Rules (IFR) throughput in Dallas Fort Worth (DFW) airport gain averaged 6% with deployment of AVOSS, a NASA experimental wake vortex avoid prototype system designed to allow reduced aircraft separations. The capacity gain would result in as much as 40% delay reduction at airports that are operating near capacity limits. (Xie, 2005)

The early researchers of queuing studies widely accepted the definition of a runway's capacity as the rate of movements under saturation, and the capacity as the reciprocal of the minimum permissible time spacing between succeeding aircrafts (Bell, 1949). The simple approximation assumes constant aircraft speed and ignores the difference of fleet mixes. In a more complicated model, Blumstein (1959) considers more realistic factors, such as initial separation prior to the final approach and velocity differences between two successive aircrafts. The Blumstein's analytical model of runway capacity is simple, and it can effectively assess impacts on capacity of changes in ATC rules and operational procedures. The primary limitation of this analytical model is its deterministic assumptions of constant aircraft speed, runway occupancy time, and distance between aircrafts, which are stochastic in reality (Xie, 2005).

In contrast to analytical models, the classical approach of simulation modeling is to create objects that move through the airspace segments and airports of interest. By observing the flows of such objects past specific locations and the amount of time it takes for aircraft to move between such points, the simulation models compute appropriate measures of capacity and delay. A detailed description of existing simulation models can be found in Odoni (*et al.* 1997).

On the other hand, Taxiways provide the necessary link between various parts of the airport, including to the gate, apron and runway system. Figure 2.2 shows schematically the basic functions served.

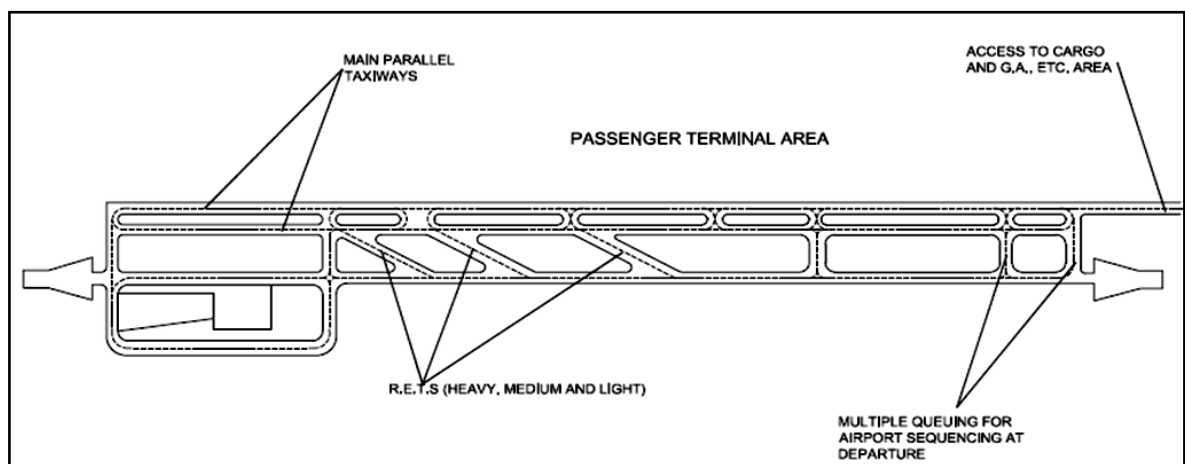


Figure 2.2. Functional Design of a Taxiway System (IATA, 2004)

The taxiway system should be designed so as to optimize runway throughput. Implementation of taxiway functionality such as Rapid Exit Taxiways (RETs), parallel taxiways and departing multiple queuing taxiways improve the system capacity. RET vacate landing aircraft from the runway at fast speeds. They are designed to minimize runway occupancy time (ROT) and therefore create necessary conditions to optimize runway utilization, since a succeeding aircraft cannot touch down until preceding aircraft clears the runway.

The apron provides direct access to aircraft stands for purposes of loading and unloading passengers, mail or cargo, or for fueling, parking or maintenance. Apron and gate design should reflect the various characteristics and volume of traffic to be handled. Significant ground delays can be experienced on apron as they are an aircraft flow merging point and provide an entry/exit point to aircraft for pushing back and powering up engines.

An aircraft stand is a designated area intended for parking an aircraft where passengers can be loaded or unloaded with a bridge or by bus. The number of stands and aircraft parking positions for different types/sizes aircrafts are calculated to meet the current and future year requirements up to ultimate runway capacity. Gate (contact) stands have a significant impact on the quality of service to users because they provide for more rapid and comfortable handling of passengers, avoid the need of buses, and enable better turnaround times. Stand Occupancy time is an important factor in establishing capacity. When conducting a gate assessment study, the processing and servicing time in Table 2.1 should be considered.

Table 2.1. Typical Aircraft Processing and Servicing Time (in min) at Stand (IATA, 2004)

AIRCRAFT TYPE	PAX LOAD	LOAD PASSENGER	UNLOAD PASSENGER	AIRCRAFT SERVING	THROUGH FLIGHT	TURNAROUND FLIGHT
<b>B</b>	40	10	5	10	-	25
<b>C</b>	130	20	10	15	25	45
<b>D</b>	250	30	15	30	45	75
<b>E</b>	1 DOOR	350	40	25	45	110
	2 DOORS	350	25	15	45	85
<b>F</b>	1 DOOR	470	55	30	80	165
	2 DOORS	470	30	20	80	130

Aircraft types given in Table 2.1 are described according to the aircraft wing spans. Codes with letters are used by ICAO, same coding system are used in FAA by roman numbers. Both coding system are explained in Table 2.2 below:

Table 2.2. Aircraft Codes according to ICAO and FAA (de Neufville and Odoni, 2003)

ICAO Code	Wing Span	FAA Code
A	$WS < 15 \text{ m}$	I
B	$15 \text{ m} \leq WS < 24 \text{ m}$	II
C	$24 \text{ m} \leq WS < 36 \text{ m}$	III
D	$36 \text{ m} \leq WS < 52 \text{ m}$	IV
E	$52 \text{ m} \leq WS < 65 \text{ m}$	V
F	$65 \text{ m} \leq WS < 80 \text{ m}$	VI

### 2.1.2 Landside Capacity

Main element of landside capacity is terminal capacity. There are also other elements such as vehicle parking areas and regional road network connected to airport. However, these are interconnected with other disciplines and to be analyzed separately. Thus, these elements are out of the scope of this study. Consequently, factors affecting terminal capacity will be explained in this section.

The airport terminal capacity planning problem deals with determining the optimal design and expansion capacities for different areas of the terminal in the presence of uncertainty with regards to future demand levels and expansion costs. Analytical modeling of passenger flow in airport terminals under transient demand patterns is especially difficult due to the complex structure of a terminal. Because of this difficulty, the airport terminal capacity planning problem has not been studied in a holistic fashion, such that studies in this area either do not account for expandability or focus only on one particular area of the terminal. (Solak *et al.*, 2009)

Terminal design and level of service should reflect the various characteristics including volume of passengers and baggage to be handled. Managing terminal capacity and designing with level of service in mind are key requirements in the development of

competitive airports. Planners must keep in mind that passengers visit an airport for one primary reason: to catch a flight. The mark of a successful airport is its natural and unobstructed passenger flow and easy navigation through the terminal, simplicity and cost-effectiveness. Level of service can be considered as a range of these values, or as assessment of the ability of supply to meet demand. To allow comparison among the various systems and subsystems of the airport and to reflect the dynamic nature of demand upon a facility, a range of level of service measures from A through to F may be used, similar to the standard employed in highway traffic engineering. These levels are illustrated in Table 2.3.

Table 2.3. Level of Service Framework (IATA, 2004)

Level of Service	Service Measure Criteria
A	An excellent level of service, conditions of free flow, no delays and excellent levels of comfort.
B	High level of service, conditions of stable flow, very few delays and high levels of comfort.
C	Good level of service, conditions of stable flow, acceptable delays and good levels of comfort.
D	Adequate level of service, conditions of unstable flow, acceptable delays for short periods of time and adequate levels of comfort.
E	Inadequate level of service, conditions of unstable flow, unacceptable delays and inadequate levels of comfort.
F	Unacceptable level of service, conditions of cross-flows, system breakdowns and unacceptable delays; inadequate levels of comfort.

The framework of level of service measures permits comparison between often unrelated subsystems within the airport complex. This aids management in the evaluation of airport components through the use of common terminology. It is much easier to describe level of service in this manner and to achieve capacity balance. Level of service C is recommended as minimum design objective, as it denotes good service at reasonable cost. Level of service A is seen as having no upper bound. The total number of passengers in an area provided for queuing tends to be fairly constant for any given flight. The space per occupant when the queue overflows is seen by IATA as the border between level of service C and D.

Capacity is a measure of throughput or system capability. Since a terminal system is capable of operating at varying degrees of congestion and delay, capacity must be related to the level of service being provided. Unlike the runway, where the laws of physics are used to calculate the capacity, the capacity of passenger terminal relates directly to the extent of congestion that will be tolerated. The sustainable capacity which is defined as the number of movements per hour that can be reasonably sustained over a period of several hours, should be based on level of service C standards for each subsystem. These subsystems are summarized in the succeeding paragraphs individually by stating relevant level of service standards in tabular forms.

Whenever any passenger enters into the airport, the first aim is to reach the check-in area as soon as possible. The area around the check-in facility should be large enough to accommodate passengers' friends without interference with the check-in process. Otherwise, the layout of the passenger check-in section of the building should permit the separation of passengers from their friends at this point. It is recommended to use four different sets of space standards at check-in, unless site specific standards are available. The classification is based on the characteristics described in below Table 2.4.

Table 2.4. Level of Service Standards ( $m^2$ /Occupant) at Check-in for Single Queue (IATA, 2004)

Space Standards	Level of Service				
	A	B	C	D	E
1. Few cart and few passengers with check in luggage (row width 1.2m).	1,7	1,4	1,2	1,1	0,9
2. Few carts and 1 or 2 pieces of luggage per passenger (row width 1.2m).	1,8	1,5	1,3	1,2	1,1
3. High percentage of passengers using carts (row width 1.4m).	2,3	1,9	1,7	1,6	1,5
4. "Heavy" flights with 2 or more items per passenger and a high percentage of passengers using carts (row width 1.4m).	2,6	2,3	2,0	1,9	1,8

Another important aspect of the terminal that affects the capacity is waiting and circulation areas. The occupancy and flow in these areas should be considered when level

of service and capacity calculated. In Table 2.5, space and speed for level of service C in various wait/circulate areas of the terminal is illustrated.

Table 2.5. Space and Speed for Level of Service C (IATA, 2004)

Description	Space (m <sup>2</sup> /pax)	Speed (m/s)
Airside- no carts	1,5	1,3
Public area after check-in - few carts	1,8	1,1
Departure before check-in - carts	2,3	0,9

Passport control is also essential system and similar to check-in system. Passport control queue system can be managed in two ways as shown in Figure 2.3.

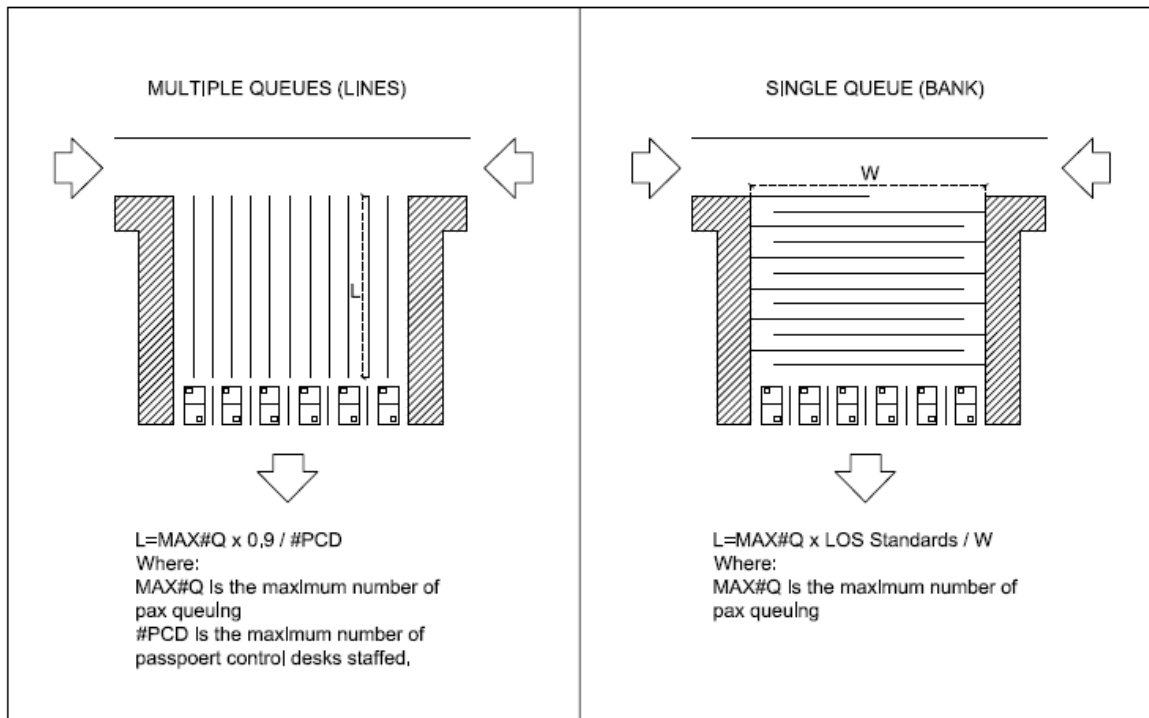


Figure 2.3. Passport Control Desks and Queuing Space Requirements (IATA, 2004)

The main criterion for determining the queue length for multiple queue systems is the average distance between two individuals waiting in the same line. It is recommended

to use 0.8 to 0.9 meters, less than this is also possible but could conflict with other passengers or carryon luggage. Space requirement for a single queue is shown in Table 2.6.

Table 2.6. Level of Service (A to E) for a Single (Bank) Queue at Passport Control  
(IATA, 2004)

	Required Space related to LOS				
	A	B	C	D	E
Passport control (sqm)	1,4	1,2	1	0,8	0,6

The space around baggage claim unit serves distinct functions. The baggage claim unit frontage provides the required positions or channels for the passenger to wait and collect their luggage. The retrieval area is effectively the space required for the motion of retrieving a suitcase. The peripheral area is used; to wait for an opening in the retrieval area; for a passenger waiting for a spouse or friend to collect their luggage; to park the cart; and to circulate in/out of the retrieval area. Figure 2.4 shows a typical layout of baggage claim unit with approximate dimensions of each area.

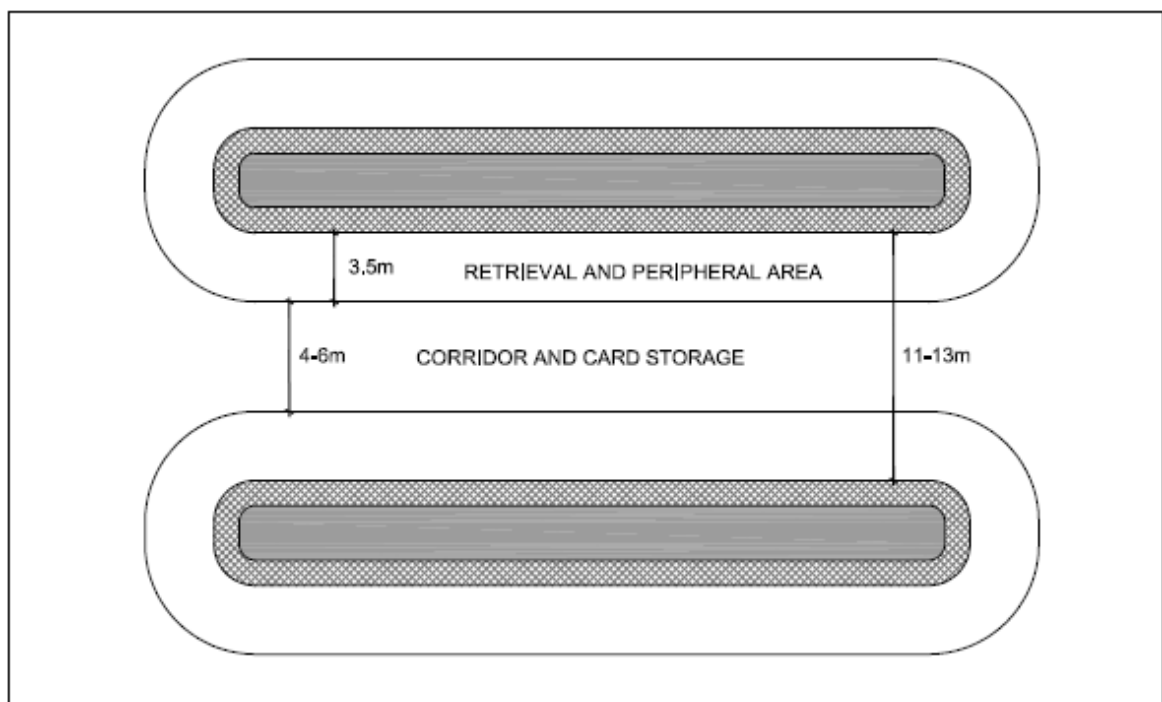


Figure 2.4. Baggage Claim system Layout (IATA, 2004)

The retrieval and peripheral area is roughly 3.5 meter wide band around the unit. This area is used to measure the level of service for the passengers waiting around the carousel and the static capacity of the unit. The capacity can be determined by dividing the total area by level of service C space standard shown in Table 2.7.

Table 2.7. Level of service for Baggage Claim Unit (IATA, 2004)

	Level of Service				
	A	B	C	D	E
Space standard (m <sup>2</sup> / occupant)	2,6	2	1,7	1,3	1

## 2.2. Demand Forecast

Airport master plans are developed on the basis of forecasts for passengers and cargo. From forecasts, the relationship between demand and the capacity of an airport's various facilities can be established and airport requirements can be determined (Wells and Young, 2004).

Airport traffic forecast studies use a combination of trend analyses, data extrapolation, expectation surveys and professional statistical judgments. Therefore, extensive operational knowledge and a comprehensive understanding of how the local environment in which the airport is situated is required (IATA, 2004).

However, the forecasting of future demand is a difficult and uncertain procedure. When forecasts are incorrect, an entire transportation mode is either deficient in its ability to provide for future traffic or suffering from overinvestment and poor economic performance (Ashford *et al.*, 1997). An accurate forecast is preferred to construct high quality air transportation facilities and services at a rational cost with minimum environmental impact and to boost economic activities. An accurate forecast is essential since the capacity planning; such as sizing and the phasing of the airport project, is dependent on the airport traffic forecast. A close working relationship with planning and

forecasting experts of all major airlines operating at the subject airport is also necessary. It is also necessary to compile a comprehensive financial and cost benefit study with an understanding of the likely aircraft movements.

Three parameters of the required data for a clear traffic forecast are passenger and baggage volumes, commercial aircraft movement and cargo. Conventionally, forecasting of future traffic demand has been carried out at the macroscopic scale, viewing demand as a response to the overall levels of change of one or more variables.

The relationship of the annual peak period will demand on seasonal variations and passenger characteristics. To establish a schedule of development for improvements proposed in the master plan to reflect typical peak period demand generated by airport transport activity, traffic forecasts often are presented projection periods such as Short Term (1 to 5 year projection), Long Term (5 to 30 year projection), Annual (12 months projection) and Peak Period (selected months within an operational year) (Wells and Young, 2004).

A combination of several methods, classified as qualitative and quantitative, forms the core of the traffic forecasting approach.

Qualitative forecasting methods uses predominantly surveyed or historic data which is then subjectively assessed by the foresight that certain experts have, based on their knowledge and experience with the airport and surrounding environment. Qualitative forecasts may almost be thought of as “educated guesses,” opinions, or “hunches” of future activity, although they tend to be just as accurate as quantitative methods. Despite this, qualitative forecasts tend to require the support of some quantitative analysis to justify the forecasts to the public (Wells and Young, 2004). It is useful in conjunction with the other methods, where there are a large number of variables for which little information is available, or where non-quantifiable factors are expected to play a major role.

This subjective assessment may take into account a wide range of real process changes, technology changes and logical factors which might affect the forecast (IATA, 2004). Four of the more popular qualitative methods include: Jury of Executive Opinion,

Sales Force Composite, Consumer Market Survey, and the Delphi method (Wells and Young, 2004).

The Jury of Executive Opinion method seeks the predictions of management and administration of the airport and the airport's tenants. Given that these persons are the closest to the day-to-day operations of the airport, and typically have extensive experience in airport activity at this airport and perhaps others as well, the Jury of Executive Opinion tends to yield fairly accurate qualitative forecasts (Wells and Young, 2004).

The Sales Force Composite method seeks the judgment of airport employees, and the employees of those firms that do business at the airport for their predictions of future activity. The theory behind this method is that the employees, or "sales force," of the airport have direct interaction with the users of the airport, and may provide accurate judgments as to future activity based on this interaction. In this method human judgment and ratings are turned into quantitative estimates. Market research, industry surveys and historical analogy is used. A consumer market survey seeks the opinions of the consumer base of the airport, specifically airport passengers, cargo shippers, and users of aeronautically and non-aeronautically based businesses located in the airport vicinity and the surrounding community. Because it's this population that will actually partake in airport activity in the future, soliciting this population's judgment through a consumer market survey is a reasonable qualitative forecasting method (Wells and Young, 2004).

To bring data in a logical, unbiased and systematic way such that all information and judgments related to growth/decline can be calculated and assessed. The Delphi method is a qualitative forecasting method originally developed by marketing researchers in private sector businesses. In the Delphi method, a group of experts in the field of interest are identified and each individual is sent a questionnaire. The experts are kept apart and are unknown to each other. The independent nature of the process ensures that the responses are truly independent and not influenced by others in the group. This forecasting method involves an iterative process in which all the responses and supporting arguments are shared with the other participants, who then respond by revising or giving further arguments in support of their answers. After the process has been repeated several times, a consensus develops (Wells and Young, 2004). In general, however, the surveys of

expectations are more suitable to aggregate forecasts at the regional or national levels than to disaggregate at the airport level (Ashford and Wright, 1992).

Qualitative forecasting for the purposes of airport master planning may, and often do, use one or more of the above methods to derive initial forecast results. The subjective assessment may take a wide range of real process changes, technology changes and logical factors which might affect the forecast (IATA, 2004).

Qualitative forecasting looks at experience over time and attempts to continue the curve of historical demand in the light of general prognostications of overall conditions. On the other hand, quantitative forecasting methods are those that use numerical data and mathematical models to derive numerical forecasts. In contrast to qualitative methods, quantitative methods are strictly objective. Quantitative methods endeavor to overcome the grosser errors of qualitative forecasting in the trip generation by attempting to relate the level of traffic to changes in the level of a variety of causal or closely associated factors (Kanafani, 1981). Quantitative methods are either used as stand-alone forecasting methods, or used to support forecasts made under qualitative methods.

Quantitative methods include time-series or trend analysis models, which forecast future values strictly on the basis of historical data collected over time, and causal models, which attempt to make accurate predictions of the future on the basis of how one area of historical data affects another (Wells and Young, 2004).

Causal models use sophisticated statistical and other mathematical methods that are developed and tested by using historical data. This approach is constructed by finding variables that explain a statistical relationship between the forecasted (dependent) variable and one or more explanatory (independent) variables to be forecasted. A statistical correlation analysis is used as a basis for prediction or forecasting. Correlation is a pattern or relationship between two or more variables; the closer the relationship, the greater the degree of correlation. For example, the number of aircraft operations forecast to occur at a general aviation airport may be statistically correlated to the strength of the economy, perhaps measured by the average income of residents in the area surrounding the airport. Shortly this method relies on the assessment of socio economic variables that can cause air

traffic growth or decline. Causal models identify the socio-economic variables that can cause changes in air traffic by being ensured that historical trends for these variables are available.

The developments of causal models that are hoped to make accurate predictions of future activity require significant amounts of research into all areas of the airport environment. Not until a comprehensive causal analysis is performed using a wide variety of potential explanatory characteristics will accurate forecast results be potentially achieved. As changes occur in these variables across the area being investigated, changes in demand levels can be predicted; these predictive procedures are capable of reflecting realistic changes over time in a manner that cannot be hoped for in qualitative forecasting.

Another reasonably sophisticated statistical method of forecasting is time-series or trend analysis, the oldest and in many cases still the most widely used method of forecasting air transportation demand (Wells and Young, 2004). Time-series models are based on a measure of time (months, quarters, years, etc.) as the independent or explanatory variable. This method is used quite frequently where both time and data are limited, such as in forecasting a single variable, for example, cargo tonnage, where historical data are obtained for that particular variable.

Forecasting by time-series or trend analysis actually consists of interpreting the historical sequence and applying the interpretation to the immediate future fitting on a mathematical line to the historical data. It assumes that outside factors will continue to operate in the same way in the future to influence the rate of growth or change. Historical data are plotted on a graph, and a trend line is drawn by the projection of the mathematical line. Frequently a straight line, following the trend line, is drawn for the future; however, if certain known factors indicate that the rate will increase in the future; the line might be curved upward. As a general rule, there might be several future projections, depending upon the length of the historical period studied.

When a forecast is needed, a trend line is established and then projected out to some future period around the historical data that airport authorities keep numerous of particular concern such as emplacements, aircraft movements, number of based aircraft,

etc. Long term trends, such as market growths caused by increase in the population; cyclical variations, such as those caused by the business cycle; seasonal phenomena, such as weather or holidays; and irregular or unique phenomena, such as strikes, wars, special events, and natural disasters determines the values for the forecasted variable as the time related factors. The accuracy of forecasting by historical sequence in time or trend analysis depends on good judgment in predicting those changing factors that might keep history from repeating.

The most widely used mathematical method for performing both time-series and causal quantitative forecasts are regression analysis (Wells and Young, 2004). Regression analysis applies specific mathematical formulas to estimate forecast equations. These equations may then be used to forecast future activity by applying the equations to independent variables that may occur in the future. Regression equations come in many forms. The analysis is usually carried out by observing air trip generations from survey data and recording associated levels and changes of levels of socio economic data of the area and the philosophical characteristics of the overall origin-to-destination air-ground transport system (Ashford and Wright, 1992). The most common regression equation is one that represents a straight line. The method used to estimate the equation of a straight line that best represents either historical trends or causal relationships is known as ordinary least-squares (OLS) linear regression analysis.

Although based in sophisticated theories of statistics and calculus, OLS linear regression analysis tools are readily available on most personal computer spreadsheet software such as Microsoft Excel, Corel Quattro Pro, or IBM's Lotus 1-2-3. Other common statistical software tools available for personal computers include SPSS, SAS, and a variety programming languages that may be used to create custom regression models. All that is required of the forecaster is to collect appropriate data, enter the data into a software program, and apply the regression tool. Although applying data to today's regression tools is quite simple, proper interpretation and use of regression results require at least a fundamental knowledge of regression modeling from a theoretical perspective. It is suggested that anyone who will actively participate in performing or interpreting quantitative forecast results, such as those found from regression analysis, seek additional knowledge in statistical modeling (Wells and Young, 2004).

The dawn of theoretical approaches to estimate demand at airports occurred in the late 1940s and early 1950s with the use of gravity model, which forecasts demand between pairs of cities or airports (Harvey 1951; Mayhill 1953). Initially, the objectives of such forecasts were to predict total passenger demand for a country or a large area rather than for a specific airport (Karlaftis, *et al.*, 1996). Barlett (1965) attempted to predict the number of revenue passenger miles per capita for the United States. Twenty six regression equations with various combinations of explanatory variables were run, and the best fit was achieved when the independent variables accounted for producers' durable equipment outlays and the measure for leisure time activity. However the model that was developed had a rather low  $R^2$  of 0.58.

One of the first published efforts about airport specific forecasting model was by Jacobson (1970). The model predicted the trips generated at an airport based on the average airfare per distance for all routes in the United States, and the total income per capita for the airport catchment area. The model was calibrated of eighteen years of data from the airports of Virginia and had an  $R^2$  of 0.82. A rather similar model was developed by Haney (1975) to analyze airport specific demand for St. Louis Airport. The model was a typical airport forecasting model in that the explanatory variables are socioeconomic in nature and refer to metropolitan area served by the airport. The model predicts total annual traffic at the airport and had an  $R^2$  of 0.99.

Another interesting example of placing a special effort in direction of identifying key growth factors unique in an area, is the keys of Mexico City's airport traffic by Zuniga *et al.* (1978). Approximately 20% of the population and wealth of Mexico are concentrated in the capital, and the fast growth rate of these characteristics certainly influences the future airport traffic. The models that were developed for domestic traffic included as variables the population of Mexico City and the cost of transportation. The model developed for international travel included a variable for the foreign tourist arrivals and the dummy variable for the oil crisis. Both models had  $R^2$  of over 0.98.

The review of the existing literature review that a variety of models have been developed for the forecasting of air travel demand at airports. All the models cited established an analytical relationship between travel demand and a set of independent

variables. These variables are usually socioeconomic measures, expressing affinity for air travel in the geographic area where the airport is located. A common measure of effectiveness used to evaluate the forecasting quality of the various models is the  $R^2$ .

### 3. METHODOLOGY

#### 3.1. Introduction

In this section the methodology used in the thesis is explained. In the following sections an explanation of the basic terminology that was used in the study, capacity analysis parameters and statistical methods and their performance measures that were used in the forecasting air transport demand are presented. The proposed methodology for the thesis is principally summarized in the flowchart shown in Figure 3.1.

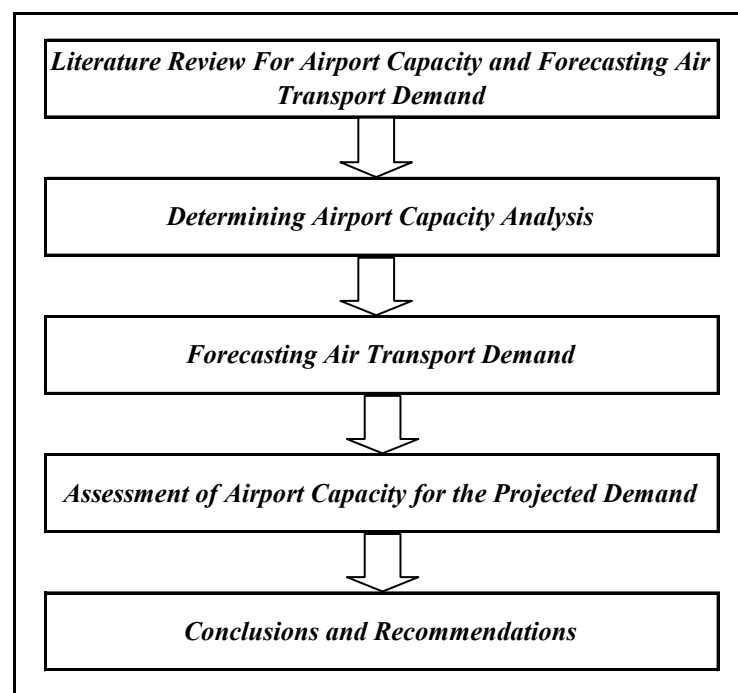


Figure 3.1. Flowchart for the thesis methodology

### 3.2. Basic Terminology and Definitions

The definitions of the terminology that was used in the research are given below:

- i. **Throughput Capacity:** The ultimate rate at which aircraft operations may be handled without regard to any small delays that might occur as a result of imperfections in operations or small random events that might occur.
- ii. **Practical Capacity:** the number of operations that may be accommodated over time with no more than a nominal amount of delay.
- iii. **Wake Turbulence (Vortex) Separation:** The required distance between two aircrafts due to effect of rotating air masses generated behind wing tips of jet aircraft which can affect aircraft operation behind them.
- iv. **RWY 18-36 :** The way of showing the geographical direction fo the runways. Numbers indicates the angles in tenths from the geographical North.
- v. **Regression Equation:** An expression of the optimal mathematical relationship between two or more related items (variables) according to a specified criterion The objective in developing the relationship between X (independent variable) and Y (dependent variable).
- vi. **Independent Variable:** A physical, measurable and predictable unit quantifying the study site (e.g., gross domestic product, tourism income).
- vii. **Dependent Variable:** The variable which is interpreted by the help of regression model created with independent variables
- viii. **Coefficient of Determination ( $R^2$ ):** A measure of what proportion of the total variation in the dependent variable is explained by the fitted model.

### 3.3. Airport Capacity Analysis

As we discussed in literature review section, the runway capacity is the critical component to overall system and runway capacity ultimately determines maximum capacity of an airport. In other systems, such as passenger terminal system, capacity could be increased by reducing level of service. In other words, other systems do not have a crucial affect on maximum capacity; however, they only affect comfort and promptness of passenger travel. Therefore, in this study we will focus on runway capacity analysis to determine the airport capacity.

Runway capacity is defined as the hourly or annually rate of aircraft operations (departures, arrivals or both, as indicated) which can reasonably be expected to be accommodated by a runway or combination of runways, under specified local conditions. The capacity of runway is not constant. Capacity varies considerably based on a number of considerations, including the utilization of runways, the type of aircraft operating, known as the fleet mix, the percentage of takeoff and landing operations being performed, and ambient climatic conditions. When a specific number is given for runway capacity at an airport, it is usually an average number based on some assumed range of conditions (Wells and Young, 2004).

The foremost factor that affects runway capacity is Wake Turbulence which determines the separation distance between two aircraft in landing or takeoff. Wake turbulence is used to describe the effect of rotating air masses generated behind wing tips of jet aircraft which can affect aircraft operation behind them. Heavier aircrafts generate more wake turbulence. Small aircrafts are more affected than heavier aircraft. It is difficult to control an aircraft too close to a leading aircraft, which is why separation minima are recommended. The classification of common types of aircrafts is given in Table 3.1:

Table 3.1. Classification of Common Aircrafts (de Neufville and Odoni, 2003)

AIRCRAFT CLASSES	AIRCRAFT	
	BRAND	TYPES
Heavy	Airbus	A300, A310, A330, A340, A380
	Boeing	747, 767, 777, MD11
Large	Airbus	A318, A319, A320, A321
	Boeing	717, 727, 737, MD81, MD87
	BAE Systems	RJX-70, RJX-80
	Bombardier	CRJ200, CRJ 700
Small	Embraer	ERJ 135
	Fairchild	328JET-310

Moreover, FAA implemented a proper procedure for wake turbulence separation minima based on aircraft mass which is tabulated in Table 3.2.

Table 3.2. Wake Vortex Separation Minima for Arrivals (de Neufville and Odoni, 2003)

PROCEEDING AIRCRAFT	SUCCEEDING AIRCRAFT	SEPERATION MINIMA
Heavy <sup>(1)</sup>	Heavy	4NM
	Large	5NM
	Small	6NM
Large <sup>(2)</sup>	Heavy	3NM <sup>(4)</sup>
	Large	3NM <sup>(4)</sup>
	Small	4NM
Small <sup>(3)</sup>	Heavy	3NM <sup>(4)</sup>
	Large	3NM <sup>(4)</sup>
	Small	3NM <sup>(4)</sup>
(1) 116 tons or more (2) Between 19 and 116 tons (3) Less than 19 tons (4) 2.5 NM minimum radar seperation on final approach is taking palce at several and should be investigated before considering constructing new runways 1 NM = 1.852 km		

Wake turbulence separation minima also apply to departures. A separation minima of 120 seconds is required after a heavy aircraft take-off. All other categories require 60 seconds separation. Accordingly, the mix of successive aircraft operating will have an impact on the overall separation and the runway capacity. For example, an airport operating majority of medium size aircraft will have an average arrival separation of 3NM. The same airport serving mix of small, medium and heavy aircraft will have a separation of 3NM to 6NM and will have a significantly reduced runway capacity. IATA proposes the following rule of thumb for different fleet mixes based on wake vortex separation and assuming a Runway Occupancy Time (ROT) of 50 seconds as given in Table 3.3.

Table 3.3. Typical Maximum Hourly Single Runway Throughput (IATA, 2004)

% HEAVY	% LARGE	DEPARTURES	LANDINGS <sup>(1)</sup>	LANDINGS <sup>(2)</sup>
25	75	48	39	+5
50	50	40	37	+3
75	25	34	36	+2

(1) Based on the wake vortex separation shown in Table 3.1.  
(2) Additional capacity assuming a 2.5 NM separation for medium size aircraft.

Another criteria affecting runway capacity is Runway Occupancy Time (ROT). A succeeding aircraft cannot touchdown until preceding aircraft clears the runway. Well-positioned exit taxiway, in other words Rapid Exit Taxiways, ensure that the time an aircraft physically spends on a runway is kept to minimum. A minimum ROT of 50-55 seconds is sought after. The spacing between successive aircraft is increased and runway capacity decreased if the 50 seconds objective cannot be achieved.

One of the characteristics that affect an airfield's capacity is the configuration of its runway system. Although every airport is different, the configurations of airport runways may be placed in the following categories: single runway, parallel runways, open-V runways, and intersecting runways. Parallel runways with adequately spacing (1035m or more) can process independent arrivals and departures. Interaction between runways is a constraint that limits capacity when the distance between runways does not meet the

minimum distance requirement or runways intersect. Although every runway configuration has a uniquely different capacity that is determined by a variety of factors, the FAA has established some basic estimates of capacity by runway configuration (Wells and Young, 2004).

In this thesis study, FAA capacity analysis approximation chart was used first for determination of runway capacity, given in Appendix A. This chart considers all the affects stated above; namely wake turbulence, runway configuration, and environmental conditions. These charts are created by assuming 50 percent arrivals and 50 percent departures. Wake turbulence effect is taken into account by using aircraft mix. Aircraft mix is expressed in terms of four aircraft classes according to maximum certified takeoff weight (MTOW) of aircraft (de Neufville and Odoni, 2003). These classes are illustrated in Table 3.4 by comparing FAA and ICAO standards:

Table 3.4. Aircraft Mix Classes Classification (de Neufville and Odoni, 2003)

AIRCRAFT CLASS		FAA	ICAO
A	small single-engine aircraft, MTOW	less than 41,000lb (~19 tons)	less than 7 tons
B	small twin-engine aircraft, MTOW	less than 41,000lb (~19 tons)	less than 7 tons
C	large aircraft, MTOW	between 41,000lb (~19 tons) and 255,000lb (~116 tons)	between 7 tons and 135 tons
D	heavy aircraft, MTOW	greater than 255,000lb (~116 tons)	greater than 135 tons

The chart employs a “mix index”, which is determined by the percentages of aircraft in classed C and D (Ashford and Wright, 1992):

$$\text{Mix index} = (\% \text{ aircraft in class C}) + 3 \times (\% \text{ aircraft in class D}) \quad (3.1)$$

In addition to aircraft mix, the capacities in FAA charts account for differences in runway configuration and weather conditions. IFR (Instrument Flight Rules) conditions exist when cloud ceiling is less than 300m or the visibility is less than 3NM. Runway is normally less under IFR conditions than the VFR (Visual Flight Rules) conditions.

Moreover, the results obtained from this chart were also verified analytically. This method can simply explained as calculation of theoretical capacity by determining minimum separation between succeeding aircrafts. However, this assessment was performed only for single runway configuration. Because, the interaction effect of converging and parallel runways was not considered. In order to consider this effect more complicated simulations should be constructed. In this method, firstly, maximum throughput capacity was calculated, and then it was converted to practical annual capacity (PANCAP).

The simple mathematical model in calculating runway capacity is originally due to Blumstein (1959). It estimates the capacity of a single runway used for arrivals. In this study it was also calculated for departures by using designated separation for take-off, and then average of these two results was taken as the expected capacity. The main idea behind the model is to calculate the separation time between aircrafts according to ATM system requirements as given above in Table 3.1.

Consider a single runway, shown schematically in Figure 10-9, which is used for landings only. Aircraft descend in single file along the final approach path until touching down on the runway, whereupon they decelerate and exit onto the taxiway system. The paths of arriving aircraft merge in the vicinity of the "gate" to the final approach, typically 5-8 NM away from the runway threshold (de Neufville and Odoni, 2003).

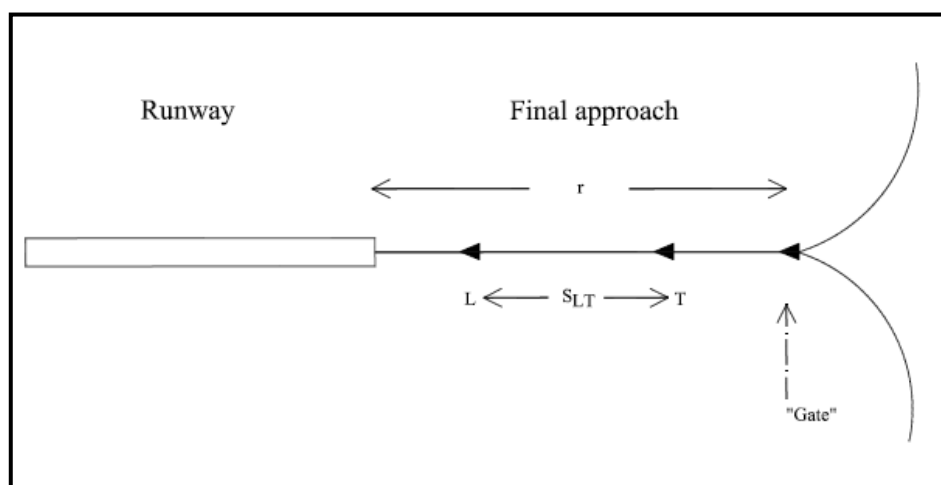


Figure 3.2. A simple representation of a runway approach (de Neufville and Odoni, 2003)

Let  $t_{ij}$  denote the minimum time interval (in the sense of not violating any ATM separation requirements) between two successive arrivals at the runway of the type  $i$  and type  $j$  aircraft. The two fundamental equations that determine  $t_{ij}$  can be written as follows (de Neufville and Odoni, 2003):

$$t_{ij} = \max \left[ \frac{r + s_{ij}}{v_j} - \frac{r}{v_i}, o_i \right] \quad \text{when } v_i > v_j \quad (3.2)$$

$$t_{ij} = \max \left[ \frac{s_{ij}}{v_j}, o_i \right] \quad \text{when } v_i < v_j \quad (3.3)$$

where;

$t_{ij}$  = minimum time interval between two successive type  $i$  and  $j$  aircraft (in hours)

$s_{ij}$  = separation minima between two successive type  $i$  and  $j$  aircraft (in NM)

$r$  = the length of the common final approach path (in NM)

$v_i$  = speed on final approach assuming, as a reasonable approximation, that aircraft  $i$  maintains a constant speed throughout the approach (in knots)

$o_i$  = runway occupancy time (in hours)

Suppose now that the probability of the event “a type  $i$  aircraft is followed by a type  $j$  aircraft” is  $p_{ij}$ . Then,

$$E[t_{ij}] = \sum_{i=1}^K \sum_{j=1}^K p_{ij} \cdot t_{ij} \quad (3.4)$$

where;

$E[T_{ij}]$  = expected value of  $T_{ij}$

$p_{ij}$  = probability of the event “a type  $i$  aircraft is followed by a type  $j$  aircraft”

$E[T_{ij}]$  denotes the expected value of  $T_{ij}$ , i.e., the value of  $T_{ij}$  on average, and  $K$  is the number of distinct aircraft classes. Finally, if the expected amount of time between successive landings has been computed, the maximum throughput capacity is simply given by (de Neufville and Odoni, 2003),

$$\text{Maximum throughput capacity} = \mu = \frac{1}{E[t_{ij}]} \quad (3.5)$$

where  $E[t_{ij}]$  is measured in hours per aircraft movement. Thus, hourly maximum throughput capacity is obtained. The next step is to calculate the annual capacity (PANCAP). The estimation of PANCAP requires a number of implicit or explicit assumptions concerning, at the very least: future daily demand patterns, such as assumption of 7 or 8 essentially idle hours, acceptable levels of delay, e.g., limiting operations to 85-90 percent of full capacity during the 16-17 useful hours of the day; and future seasonal demand patterns, e.g., 15 percent more operations in the summer season, on average (de Neufville and Odoni, 2003). These observations can now be generalized. Let  $A$  denote the number of annual movements obtained by multiplying the number of hours in the year (8760) by average value of the maximum throughput capacity available per hour at an airport. The annual capacity of the airport will then be equal to  $kA$ , with the coefficient  $k$  usually in the range of 0.50-0.60. Values of  $k$  in the low end of the range (0.5 – 0.55) will apply to airports with relatively sharp daily and seasonal peaking, little or no nighttime activity, and limited tolerance for long delays. Values of  $k$  in the high end of the range (0.55-0.60) will apply to airports with moderate daily and seasonal peaking, intensive utilization during all but a few nighttime hours, and high tolerance for delays (de Neufville and Odoni, 2003).

The runway capacities for both airports in Istanbul, namely Atatürk International Airport and Sabiha Gökçen International Airport were first determined according to FAA charts in the next section. Moreover, analytical method was also used for Sabiha Gökçen International Airport which has single runway configuration. Then chart and analytical result were compared. Afterwards, results were compared with the current capacities. If any differences occurred, the reasons were identified. Subsequently, related recommendations were given in order to increase the capacity to the values determined from the FAA Charts.

### 3.4. Demand Forecast Analysis

In the previous section, it was mentioned that runway capacity is the critical component to overall system and determines the maximum capacity of airport. Thus, in the thesis, scope of analysis is drawn in runway capacity which is determined by the number of aircraft movements in respective times. In order to compare this result with demand, respective forecasts were obtained.

As discussed in literature review section, two types of forecasting methods are available in estimating aircraft movement in future: qualitative and quantitative. In this thesis, the more accurate one, quantitative methods will be utilized. The aircraft movement demand shall be forecasted with regression techniques.

These statistical models for demand analysis have been widely used for many years in the prediction of urban passenger transport (Ashford, 1985). When applied to air transport, a statistical relationship is established between rate of aircraft movement (the dependent variable) and a number of predictive variables (independent variables). The analysis was carried out by observing aircraft movement survey data and recording associated levels and changes of levels of socioeconomic data of Istanbul. Firstly, the independent variables were selected logically. Then, by the use of correlation analysis, suitable predictive variables were chosen that seem to be best capable of modeling aircraft movement demand. Afterwards, regression models were constructed to describe existing relationships, and these models were used to forecast future aircraft movement demand.

Regression Models in general; use a relationship between two or more variables so that one dependent variable can be predicted from the other independent variable(s). This dependent variable may be the air plane ticket prices, number of traffic accidents, the rate of growth of a country economy, or the total aircraft movement in an airport. In all cases, this variable is called the dependent variable and represented with Y (Rawlings *et al.*, 1989) Other variables which give information on the dependent variable are integrated into the model as predictive variables. These variables are called the independent variables and are represented by X with subscripts in order to categorize different independent variables.

Assigning  $X$  to the independent variable and  $Y$  to the dependent variable respectively; for every  $X$  value inserted into the equation there will be a resultant  $Y$  value produced. The relationship between  $X$  and  $Y$  values can be generalized as in Equation given below: (Walpole *et al.*, 2001).

$$Y_i = \beta_0 + \beta_1 X_i \quad (3.6)$$

where,

$Y_i$  = The value of the dependent variable (this case number of aircraft movements)

$X_i$  = The value of the independent variable

$\beta_0, \beta_1$  = Regression coefficients

The idea of regression analysis deals with finding the best relationship between  $Y$  and  $X$ , determining the strength of that relationship, and using methods that allow for prediction of the response values given values of the independent variables. In other words, regression analysis examines the relationship between a quantitative dependent variable  $Y$  and one or more (in multiple regression analysis case) quantitative independent variables,  $X_1, \dots, X_2$ . The subscripts denote the observational unit from which the data were taken. The  $X$ 's are assumed to be known constants. In addition to the  $X$ 's, all models involve unknown constants, called parameters, which control the behavior of the model (Rawlings *et al.*, 1989). These parameters ( $\beta_0, \beta_1$ ) are denoted by Greek letters and are to be estimated from the data.

An analysis of the relationship between  $Y$  and  $X$  requires the statement of a statistical model and it must include the set  $[(x_i, y_j); i = 1, 2, \dots, n]$  of data involving  $n$  pairs of  $(x, y)$  values. The statistical model for simple linear regression takes the form of the equation below and shows how the response (dependent variable)  $Y$  is related to the independent variable  $x$ .

$$Y_i = a + \beta x + e \quad (3.7)$$

In the equation above,  $a$  and  $\beta$  are unknown intercept and slope parameters, respectively, and  $e$  is a random variable that is assumed to be distributed with  $E(e) = 0$  and  $Var(e) = \sigma^2$ . The quantity  $\sigma^2$  is often called the error variance or residual variance (Walpole *et al.*, 2001).

The least squares estimation procedure uses the criterion that the solution must give the smallest possible sum of squared deviations of the observed  $Y_i$  from the estimates of their true means provided by the solution. Let  $\hat{\beta}_0$  and  $\hat{\beta}_1$  be numerical estimates of the parameters  $\beta_0$  and  $\beta_1$ , respectively.

$$\hat{Y}_i = \hat{\beta}_0 + \hat{\beta}_1 X_i \quad (3.8)$$

Let the previous equation be the estimated mean of  $Y$  for each  $X_i = 1, \dots, n$ . The least squares principle chooses  $\hat{\beta}_0$  and  $\hat{\beta}_1$  that minimize the sum of squares of the residuals (Rawlings *et al.*, 1998). In other words, the least squares method of regression minimizes the squares of the differences between actual points of a data set and points predicted by a linear equation. These squares of the errors are added up and the total is called the Residual Sum of Squares (RSS) and the calculation of RSS is shown in Equation below.

$$RSS = \sum_{i=1}^n (Y_i - \hat{Y}_i)^2 = \sum (e_i^2) \quad (3.9)$$

The most common criterion for comparing the goodness-of-fit of regression models is the Coefficient of Determination (Coefficient of Multiple Correlation), or  $R^2$ . Mathematically it is defined as:

$$R^2 = \frac{SSR}{SST} = \frac{\sum_{i=1}^n (\hat{y}_i - \bar{y})^2}{\sum_{i=1}^n (y_i - \bar{y})^2} \quad (3.10)$$

where,

SSR = Regression Sum of Squares

SST = Error Sum of Squares

This is the proportion of the (corrected) sum of squares of  $Y$  attributable to the information obtained from the independent variable(s). The coefficient of determination ranges from zero to one and is the square of the product moment correlation between  $Y_i$  and  $\hat{Y}_i$ . If there is only one independent variable, it is also the square of the correlation coefficient between  $Y_i$  and  $X_i$  (Rawlings *et al.*, 1989).

The Coefficient of Determination is an indicator of how much of the variation in the dependent variable is explained with the independent variables included in the regression model.

## **4. AIRPORT CAPACITY**

### **4.1. Introduction**

In this section the capacity of the Airports in Istanbul was determined as explained in the previous section. The analysis was performed for runway capacity. Furthermore, a general overview for other elements of airport and their respective capacities were discussed.

Firstly, the leading airport of the Istanbul, Atatürk International Airport was analyzed in detail. The current capacity problems and their effects were summarized after determination of capacity. Following this, the second airport of Istanbul, Sabiha Gökçen Airport was assessed in terms of its runway capacity. Since, Sabiha Gökçen Airport is utilized under its capacity currently, only the runway capacity analysis was discussed.

### **4.2. Atatürk International Airport**

Atatürk International Airport can be considered as gateway to the world and the air traffic hub of Turkey. Around 40 percent of the all aircraft movements and more than 50 percent of the all international flights are accommodated by Atatürk International Airport. Operation of terminal is performed by TAV<sup>1</sup> since 2000 after Built-Operate-Transfer (BOT) tender of International Terminal construction was won by them.

There are three terminals in Istanbul Atatürk Airport; International Terminal, Domestic Terminal and General Aviation Terminal. The International terminal has a 20 million annual passenger capacity with the key figures given below:

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<sup>1</sup> TAV : Tepe Akfen Airports Holding Corporation

Terminal Building Area	264.000 m <sup>2</sup>
Car Park Area	179.000 m <sup>2</sup>
Car Park Capacity	7076 cars
Passenger Boarding Bridges	23 units
Remote Boarding Gates	12 units
Check-in Counters	224 units
Baggage Claim Carousels	11 units

In the preparation period of this thesis, an extension project of 18,000 m<sup>2</sup> additional terminal area, 29.500 m<sup>2</sup> car park and 3 passenger boarding bridge was on progress. Thus; the capacity of the terminal is expected to increase. On the other hand, domestic terminal has a capacity of 10 million annual passengers and the key figures mentioned below:

Terminal Area	54.000 m <sup>2</sup>
Check-in Counters	108 units
Baggage Carousels	5 Units
Passenger Boarding Bridges	9 Units

The part of extension project mentioned above has also contribution to domestic terminal. In this respect, additional 6 passenger boarding bridges shall be installed and 2.500 m<sup>2</sup> of area shall be refurbished. It can be concluded that by the help of the on-going extension project and some more operational enhancements, Atatürk International Airport is expected to able to accommodate approximately 35 million passengers annually.

Atatürk International Airport accommodates between 700 and 800 movements a day, including more than 80% medium-jets. A peak of 904 movements was experienced in 2009. Some 276,148 movements and 28,553,132 passengers were accommodated in 2008 (DHMI).

As shown in Figure 4.1, Atatürk International Airport is equipped with converging runways 06/24, 18L/36R and 18R/36L. Runway 06/24 is 2300 m long, 60 m wide, while RWY 18L/36R is 3000 meters long, 45 m wide and RWY 18R/36L is 3000 m long and

45m wide. Runways 18L/36R and 18R/36L are separated by 215 meters, thus they cannot process independent movements.



Figure 4.1. Atatürk International Airport Layout

The runway configuration of Atatürk Airport is converging. The predominant direction of runway operations is A06/D36 (arrivals on RWY 06 and departures on RWY 36) which is able to accommodate large and heavy aircrafts. This configuration is the 18th item in the FAA chart given in Table 4.1.

Table 4.1. FAA Capacity Analysis Chart for Atatürk International Airport

Runway Configuration Diagram	Mix Index-- Percent(C+3D)	Hourly Capacity (operations per hour)		Annual Service Volume (operations per year)
		VFR	IFR	
	0 to 20	295	59	385.000
	21 to 50	210	57	305.000
	51 to 80	164	56	275.000
	81 to 120	146	59	300.000
	121 to 180	129	60	355.000

In order to estimate Annual Service Volume from the chart, mix index should be calculated. DHMI staff has collected data in September 2008 in this respect. According to this data, average daily movement was 748. Out of this number, 72 of them was heavy aircraft (Code D), 640 of them was large aircraft (Code C). The remaining aircrafts are small aircrafts which are not taken into consideration while calculating mix index according to Equation 3.1. The mix index for 2008 can be calculated as stated in following:

$$\text{Mix index}_{2008} = \left(\frac{640}{748}\right) \times 100 + 3 \cdot \left(\frac{72}{748}\right) \times 100 = 114 \quad (4.1)$$

As we can read from the Table 4.1, the respective Annual Service Volume Capacity is 300,000 movements. However, Istanbul has the potential of being a hub terminal between Far East and Europe, America which are done by heavy aircrafts. Thus, it is expected that by 2024 the ratio of heavy aircrafts will increase in Istanbul. We can expect that, the percentage of large aircrafts will decrease to 75% from 85%, and the percentage of heavy aircrafts will increase to 20% from 10%. Thus, the estimated mix index for 2024 can be calculated as;

$$\text{Mix index}_{2024} = 75 + 3 \times 20 = \mathbf{135} \quad (4.2)$$

The expected Annual Service Volume Capacity of Atatürk International Airport at 2024 can be stated as 355,000 movements as seen in the Table 4.1. This capacity can even increase to 400,000 movements by implementing well-organized slot coordination.

On the other hand, currently Atatürk International airport has a capacity problem, even though total annual movement is approximately 280.000. In the peak hours, 30 minute delays exist, aircrafts are having cycles around the airport to get the permission for landing. The main reason behind that is schedule coordination mechanism. As it can be seen in Figure 4.2, majority of movements occur between 03:00 am – 09:00 pm in the model month August 2008. The remaining six hours are occupied much less than the capacity.

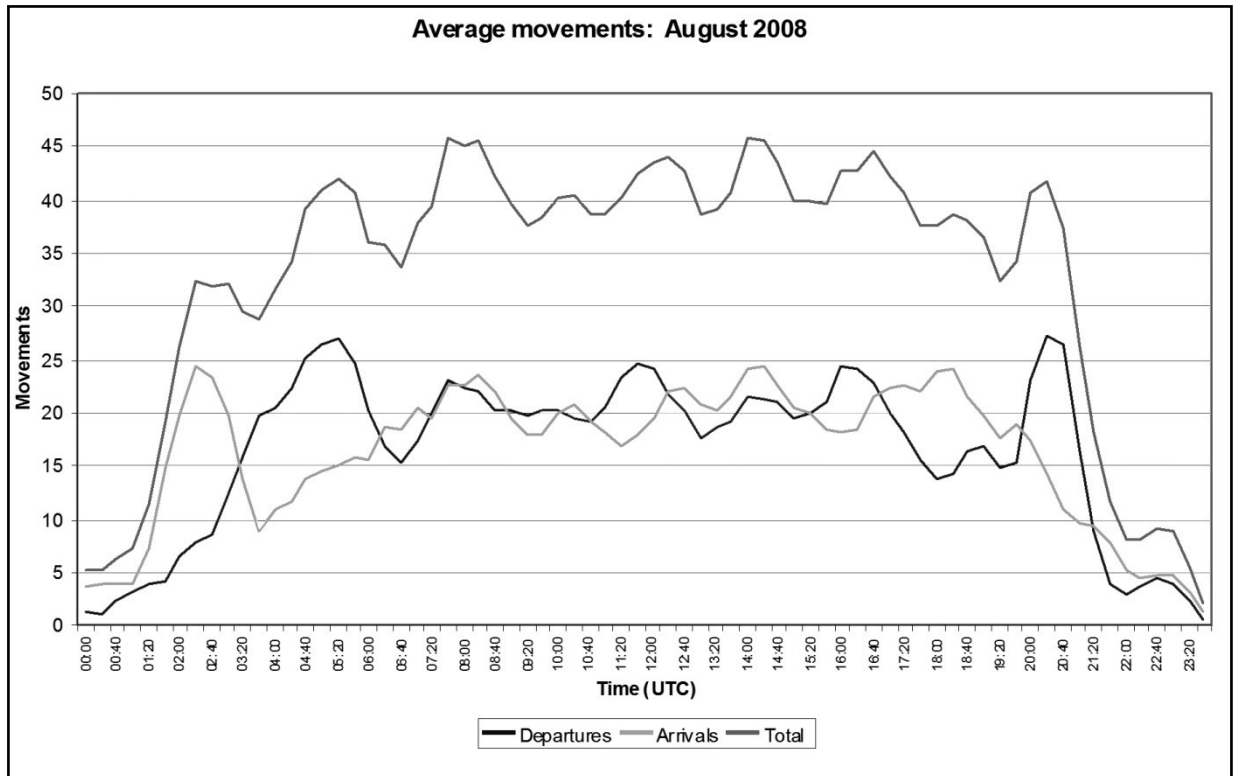


Figure 4.2. 20-minute rolling average movements (Eurocontrol, 2009)

The daily capacity can be increased by 200-250 movements by implementing more effective schedule coordination mechanism. This may imaginarily increase yearly capacity by around 70,000 movements which can relieve the current congestion of Istanbul International Airport.

Another important reason of reduced capacity in Istanbul International Airport is arrival and departure spacing between landing and taking off aircrafts. The arrival spacing for each runway configuration that has been measured by DHMI staff in 2007 and 2008 is given in Figure 4.3.

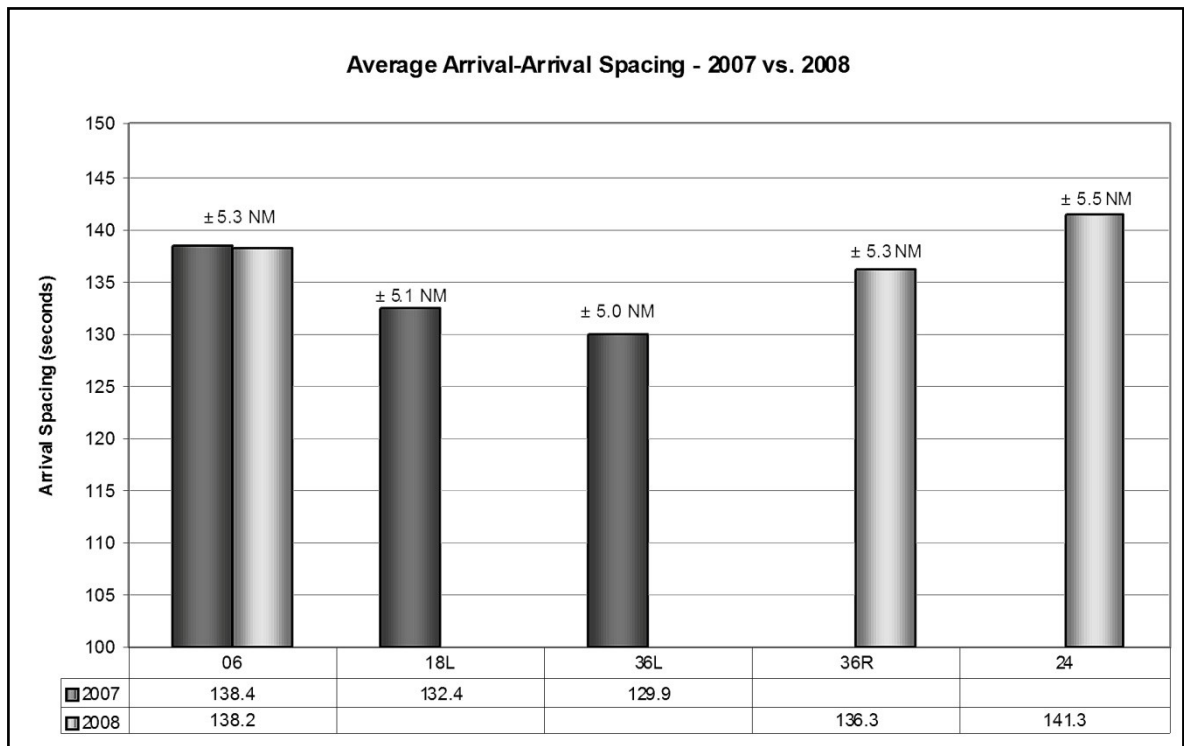


Figure 4.3. Arrival Spacing by runway configuration in 2008 and 2009 (Eurocontrol, 2009)

The average achieved arrival-arrival spacing is between 5.1 NM and 5.5 NM which is much higher than the necessary spacing stated in Table 3.1. It was stated that 85% of the aircrafts are medium and 10% is heavy aircraft. Therefore required spacing for majority aircraft is only 3 NM. An improved spacing by 1NM to 4NM could lead to an extra 5 movements per hour.

Runway occupancy time on 36R is good; less than 50 seconds for medium jet aircraft. For runway 06 however, ROT is higher with 40% of traffic using the full length of the runway. There will be a construction in runway 06 for extension of length to 2800m and addition of rapid exit taxiway which will reduce ROT.

The last parameter reducing the runway capacity of Istanbul International Airport is departure separations. In Figure 4.4, departure separations for each runway and type of aircraft are illustrated:

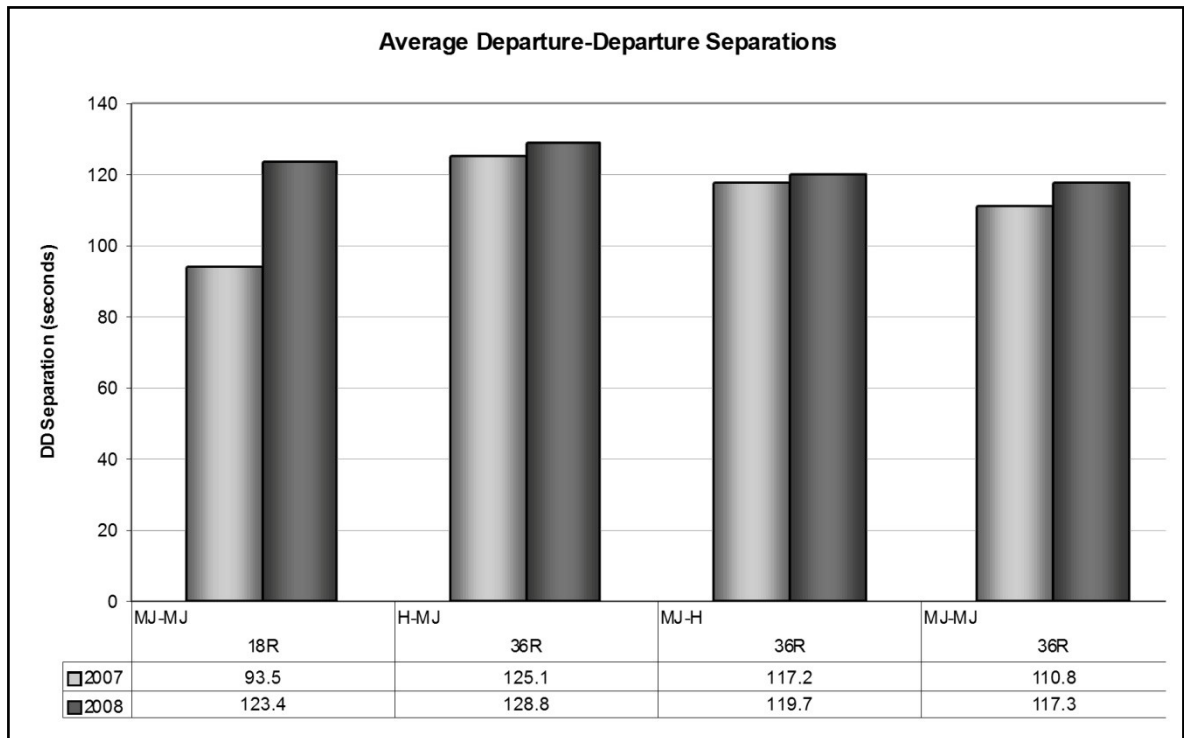


Figure 4.4. Average Departure Separations by runway configuration (Eurocontrol, 2009)

The average spacing is 120 seconds, however this is only required for following of a heavy aircraft. All other types require only 60 seconds according to ICAO rules. The capacity of runway shall be increased if this separation can be decreased to 60 seconds.

The peak hourly capacity of Istanbul International airport is currently 50 movements. It can easily be stated that this hourly capacity shall increase to 60 to 65 movements by developing solutions in the above mentioned problems. Thus, these developments enhance annual capacity of Istanbul International Airport to 355.000 as we have already determined from the FAA charts.

### 4.3. Sabiha Gökçen International Airport

Sabiha Gökçen International Airport was opened to passenger and aircraft traffic in January 2001 and was operated by Airport Operation and Aviation Industries Co. (HEAS) which is owned by Defense Industry Undersecretaries until May 2008. Operation of

terminals was conveyed to Limak – GMR – Malaysia Airports Consortium, winner of the BOT tender of “New Terminal and Components Project” in May 2008.

An additional new terminal has been designed and constructed for an annual capacity of 10 million passengers and has been inaugurated in November 2009. The key figures for the new terminal are demonstrated in Table 4.2:

Table 4.2. The key figures for the new terminal

Closed Area	227,000 m <sup>2</sup>
Car park Area	110,000 m <sup>2</sup>
Car park Capacity	4,700 m <sup>2</sup>
Passenger Boarding Bridges	8 units (double sided)
Check-in Counters	96 units
Rapid Check-in (No Baggage)	24 units
Passport Counters	20 units
Baggage Reclaim	6 units

There are also two other terminals, International and Domestic, which are being in operation since 2001 and still in operation. International Terminal has an area of 22,000m<sup>2</sup> and annual passenger capacity of 3 million. Domestic Terminal has an area of 2,000 m<sup>2</sup> and 500,000 annual passenger capacity. As a summary, Sabiha Gökçen Airport has currently annual passenger capacity of 13.5 million. This figure might be enhanced by implementing slight changes according to the future requirements.


Sabiha Gökçen International Airport accommodates between 100 and 200 movements a day. A peak of 283 movements was experienced in 2009. Some 49,507 movements and 4,281,198 passengers were accommodated in 2008 (DHMI).



Figure 4.5. Sabiha Gökçen International Airport Layout

As shown in Figure 4.3, Sabiha Gökçen International Airport is equipped with single runway 06/24 which is 3000 m long, 45 m wide. In addition to that, the current taxiway can be utilized as runway in case of maintenance of runway. The respective FAA chart for this type of runway is given in Table 4.3 below:

Table 4.3. FAA Capacity Analysis Chart for Sabiha Gökçen International Airport

Runway Configuration Diagram	Mix Index-- Percent(C+3D)	Hourly Capacity (operations per hour)		Annual Service Volume (operations per year)
		VFR	IFR	
	0 to 20	98	59	230.000
	21 to 50	74	57	195.000
	51 to 80	63	56	205.000
	81 to 120	55	53	210.000
	121 to 180	51	50	240.000

In order to estimate Annual Service Volume from the chart, mix index should be calculated. Average daily movement was 136 in 2008. Out of this number, 7 of them were

heavy aircrafts (Code D), 76 of them were large aircrafts (Code C). The mix index for 2008 can be calculated as stated in following:

$$\text{Mix index}_{2008} = \left(\frac{76}{136}\right) \times 100 + 3 \cdot \left(\frac{7}{136}\right) \times 100 = 71 \quad (4.3)$$

As we can read from Table 4.2, the respective Annual Service Volume Capacity is 205,000 movements. However, it is expected that by 2024 the ratio of heavy aircrafts will increase. We can expect that, the percentage of large aircrafts will increase, as discussed being a hub between Far East and Europe as Ataturk International Airport case, to 70% from 55%, and the percentage of heavy aircrafts will increase to 15% from 5%. Thus, the estimated mix index for 2024 can be calculated as;

$$\text{Mix index}_{2024} = 70 + 3 \times 15 = \mathbf{115} \quad (4.4)$$

Stemming from this result, the expected Annual Service Volume Capacity of Sabiha Gökçen International Airport at 2024 can be stated as 210,000 movements as seen in the Table 13.

The other capacity calculation method for single runways which has been explained in previous chapter was also utilized. In order to calculate runway capacity analytically, firstly aircraft mix, probabilities of succeeding aircraft pairs, final approach speeds and runway occupancy times should be summarized in tabular form as shown in Table 4.4 below:

Table 4.4. Aircraft Fleet Mix Details for Sabiha Gökçen International Airport

<b>Aircraft Type</b>	<b>Pair Probability</b>	<b>Approach Speed</b> $v_i$ (knots)	<b>ROT</b> $o_i$ (s)
<b>Heavy</b>	0,15	150	70
<b>Large</b>	0,7	130	60
<b>Small</b>	0,15	100	50

Afterwards, the separation time between each pair of aircrafts were calculated by using equations 3.2 and 3.3 while considering ATM separation requirements as stated in Table 3.1. The length of common approach path( $r$ ) is taken as 5 NM. The results are tabulated as a matrix form in Table 4.5 which shows the arrival separations ( $t_{ij}$ ) resulting from the calculations.

Table 4.5. Matrix  $t_{ij}$  of arrival separations for Sabiha Gökçen International Airport

		Leading Aircraft		
		<i>in sec</i>	Small	Large
Trailing Aircraft	Small	81,82	188,81	240,00
	Large	69,23	69,23	156,92
	Heavy	60,00	60,00	96,00

It is seen that runway occupancy times ( $o_i$ ) are smaller than the time separations during the approach and hence have no effect on the capacity. Next, The Matrix  $P_{ij}$  should also be determined in order to facilitate Equation 3.4 and find the average time interval between two arrivals. The Matrix  $P_{ij}$  was calculated according to the values in Table 4.4 and summarized in Table 4.6 below:

Table 4.6. Matrix  $P_{ij}$  of Pair Probabilities for Sabiha Gökçen International Airport

		Leading Aircraft		
		Small	Large	Heavy
Trailing Aircraft	Small	0,02	0,11	0,02
	Large	0,11	0,49	0,11
	Heavy	0,02	0,11	0,02

After obtaining Matrices  $t_{ij}$  and  $P_{ij}$ , Equation 3.4 was used to obtain expected amount of time between successive landings as shown in below:

$$E[t_{ij}] = \sum_{i=1}^K \sum_{j=1}^K p_{ij} \cdot t_{ij} = 94.55 \text{ sec} \quad (4.1)$$

Then, maximum throughput capacity for arrivals was simply calculated as given in Equation 3.5 as given in below and found out **38** arrivals/hour.

$$\text{Maximum throughput capacity} = \mu_{arr} = \frac{1}{E[t_{ij}]} = 38 \text{ arrivals / hour} \quad (4.2)$$

It is also required to do same analysis for departure ATM separation requirements, since; it has been assumed that 50 percent of the movements shall be departures.  $P_{ij}$  matrix remains same, but  $t_{ij}$  matrix is determined as per ATM requirements mentioned in the previous chapter and illustrated in Table 4.7 below:

Table 4.7. Matrix  $t_{ij}$  of departure separations for Sabiha Gökçen International Airport

		Leading Aircraft		
		<i>in sec</i>	Small	Large
Trailing Aircraft	Small	60	60	120
	Large	60	60	120
	Heavy	60	60	120

Again Equation 3.4 was used to obtain expected amount of time between successive departures as shown in below:

$$E[t_{ij}] = \sum_{i=1}^K \sum_{j=1}^K p_{ij} \cdot t_{ij} = 69 \text{ sec} \quad (4.3)$$

Finally, maximum throughput capacity for departures was basically calculated as given in Equation 3.5 as given in below and found out **52** departures/hour.

$$\text{Maximum throughput capacity} = \mu_{dep} = \frac{1}{E[t_{ij}]} = 52 \text{ departures / hour} \quad (4.4)$$

At last, maximum throughput capacity of the runway is calculated as **45** movements per hour by calculating the average of departure and arrival throughput capacities.

$$\mu_{ave} = \left( \frac{\mu_{dep} + \mu_{arr}}{2} \right) = \left( \frac{38 + 52}{2} \right) = 45 \text{ arrivals / hour} \quad (4.5)$$

The final step is to derive Practical Annual Capacity (PANCAP) from the maximum throughput capacity. It is stated that PANCAP is equal to “kA” where the “k” is a variable constant between 0.5-0.6 and A is the annual maximum throughput capacity. “k” can be considered as 0.55 for Sabiha Gökçen International Airport. Thus, it can be calculated as;

$$\text{PANCAP} = 0.55 \times 45 \times 24 \times 365 = 216,800 \text{ movement}$$

The capacity obtained in analytical solution is very close the capacity determined from FAA chart. Consequently, the accuracy of FAA charts is verified by analytical method. At last, the annual capacity of Sabiha Gökçen International Airport can be stated as 210,000 movement as determined from FAA chart.

#### **4.4. Total Airport Capacity of Istanbul**

In the previous two sections, runway capacities of two airports in Istanbul were determined. Moreover, general information for the passenger terminals are provided in order to monitor meeting capability of respected runway capacities.

Atatürk International Airport has a total runway capacity of 355,000 movements which will approximately create a 40 millions of passengers annually. This number of passenger can be accommodated with small extension project and operational enhancements in case of the increased demand in the future. Unfortunately, this number shall be the maximum capacity Atatürk International Airport, since; there is no available land to construct an additional runway which may increase the total airport capacity

Sabiha Gökçen International Airport has a runway capacity of 210.000 movements which shall generate around 25 millions of passengers annually. However, this number may only be accommodated by construction of additional terminals. The fortunate part of Sabiha Gökçen Airport, availability of land permits the construction of additional runways which will increase the total airport capacity. These discussions have been presented in detail in the next chapter after determining the demand.

To summarize, total of two airports runway capacity allows Istanbul to accommodate around 550,000-600,000 movements and 60-65 millions of passenger with some additional investments in terminal facilities as stated in previous sections.

## **5. DEMAND FORECAST ANALYSIS**

### **5.1. Introduction**

In this chapter, the total aircraft movement demand for Istanbul was forecasted for next 15 years in order to compare with the available capacity. While accomplishing this, regression analysis was utilized by using the historical survey data. The data that were used were taken from the governmental sources.

This chapter focuses on the calibration of the relationships between the dependent (aircraft movement) and independent variables using regression analysis. First relevant independent variables were selected logically, and then correlation matrix was constructed in order to determine the degree of relationship between all variables. Finally, regression models were calibrated. After calibrating the regression model, forecasted values of independent variables were used in the model to forecast the aircraft movement demand for the year 2024. Because of starting operations in the recent years, the historical trend for Sabiha Gökçen Airport does not reflect the future very well. Therefore, total aircraft movements were summed up for two airports and one regression model was constructed for the total demand.

Finally, the total capacity that has been determined in Chapter 4 was compared with the demand forecasts obtained in this chapter. Some remedies for congestion relief were recommended.

### **5.2. Calibration of Regression Models for Aircraft Movement Demand**

For an efficient operation of airports, it is essential to understand the trends in the dependent, i.e. the aircraft movements, variable by observing past data. The number of aircraft movements for both airports, Atatürk International Airport and Sabiha Gökçen International Airport are presented in Figure 5.1.

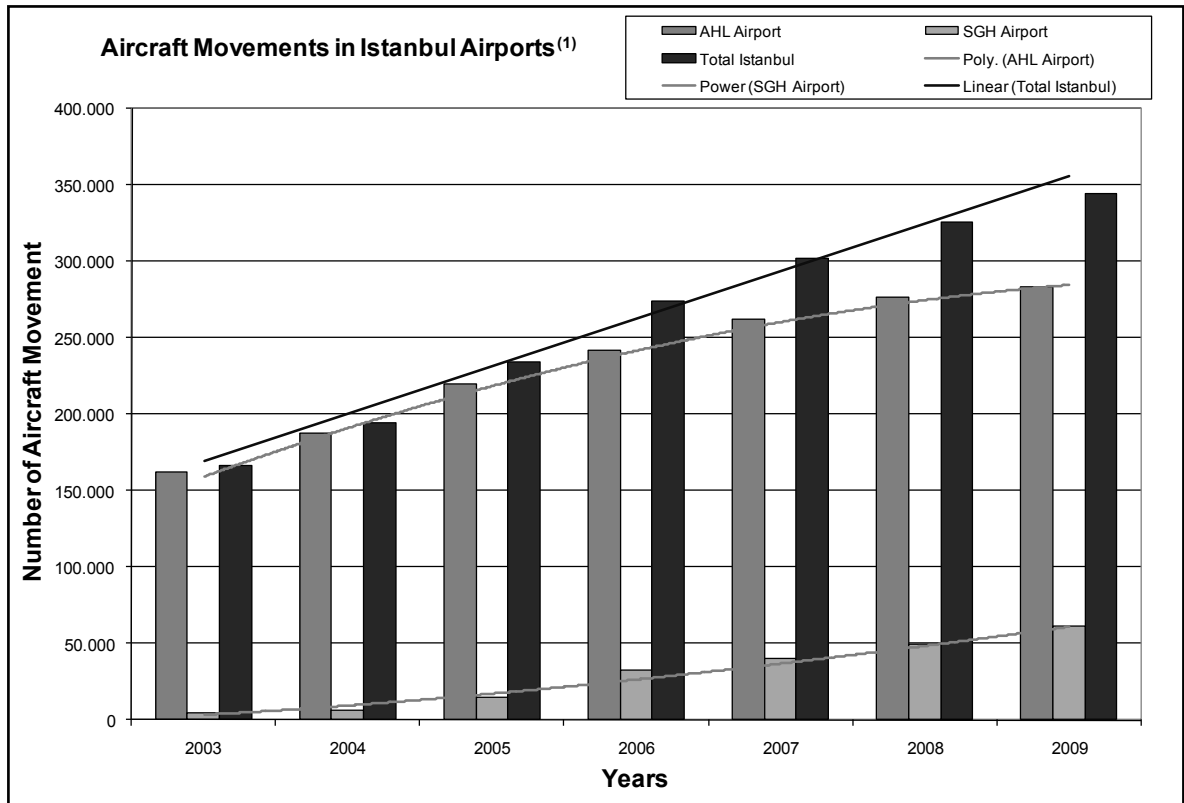


Figure 5.1. Number of Aircraft Movements in recent years<sup>2</sup> (DHMI)

It is easily seen that cumulative number of aircraft movements in Istanbul has been increasing annually. It seems that starting from 2007 Atatürk International Airport's movement rate of increase dropped. The reasons behind that are increased operations in Sabiha Gökçen International Airport and approaching its current capacity. On the other hand, the total demand for both airports shows an almost linear increase.

### 5.2.1. Identification of Independent Variables

The next step in establishing regression after having a general idea of past trend was to identify predictive (independent) variables that can explain changes in level of aircraft movement demand. Variables most commonly used for the projection of aircraft movement in an area are socioeconomic factors, such as population, income, type of

<sup>2</sup> The data are collected by DHMI. Year 2009 value was available till November, total 2009 value is estimated by extrapolation.

employment, etc. (Wells and Young, 2004). However, these variables should be in macro scale for Istanbul, since, Istanbul can be considered as Turkey's gateway to world.

First of all, Gross Domestic Product (GDP) is the key variable in forecasting air transport demand. Since, the variables shall be in macro scale, GDP per capita of Turkey shall be considered as one of the predictive variables. The historical data obtained from Turkish Statistical Institute (TUIK) is illustrated in Figure 5.2.

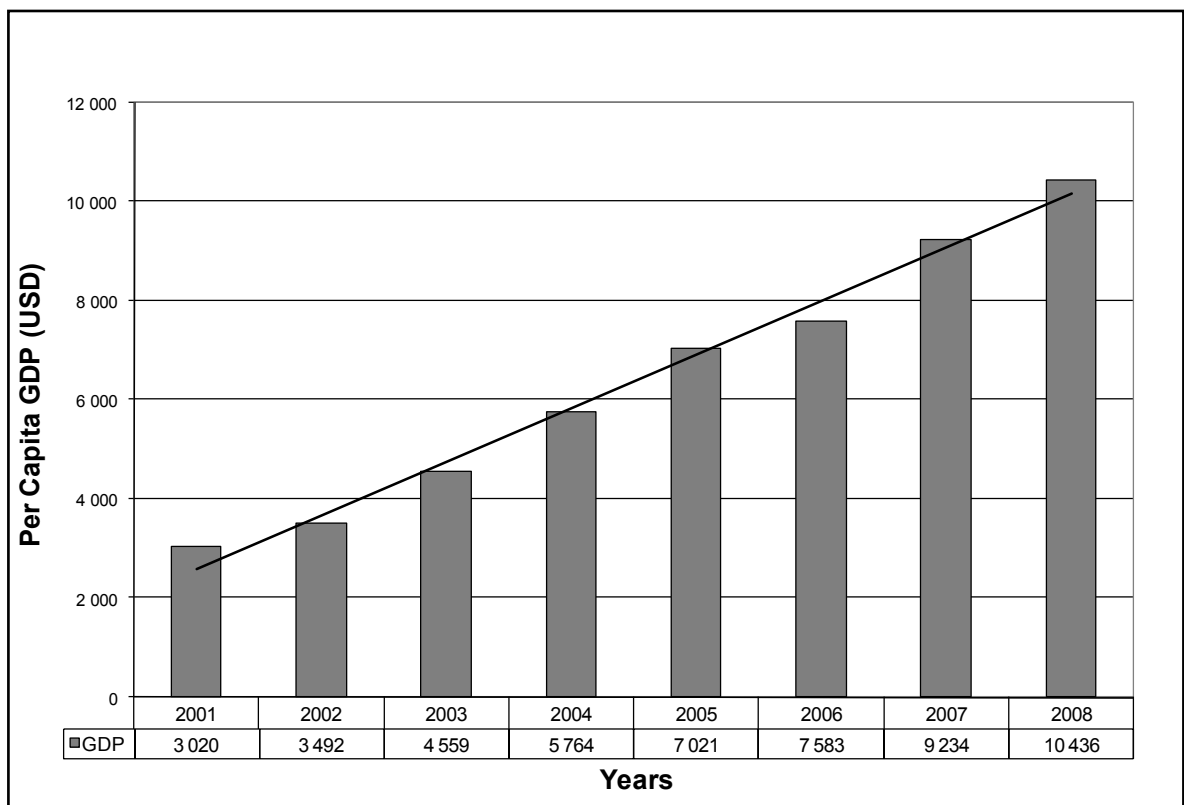


Figure 5.2. Per capita Gross Domestic (USD) in recent years (TUIK)

Secondly, population is also a predictive variable which is expected correlated to the passenger numbers, so as to aircraft movements. Moreover it, is very easy to obtain a forecasted value for population which will be plugged in the regression model in order to get the value of dependent variable over time. The historical trend of population of Turkey is illustrated in Figure 5.3, which seems in the same trend of aircraft movements.

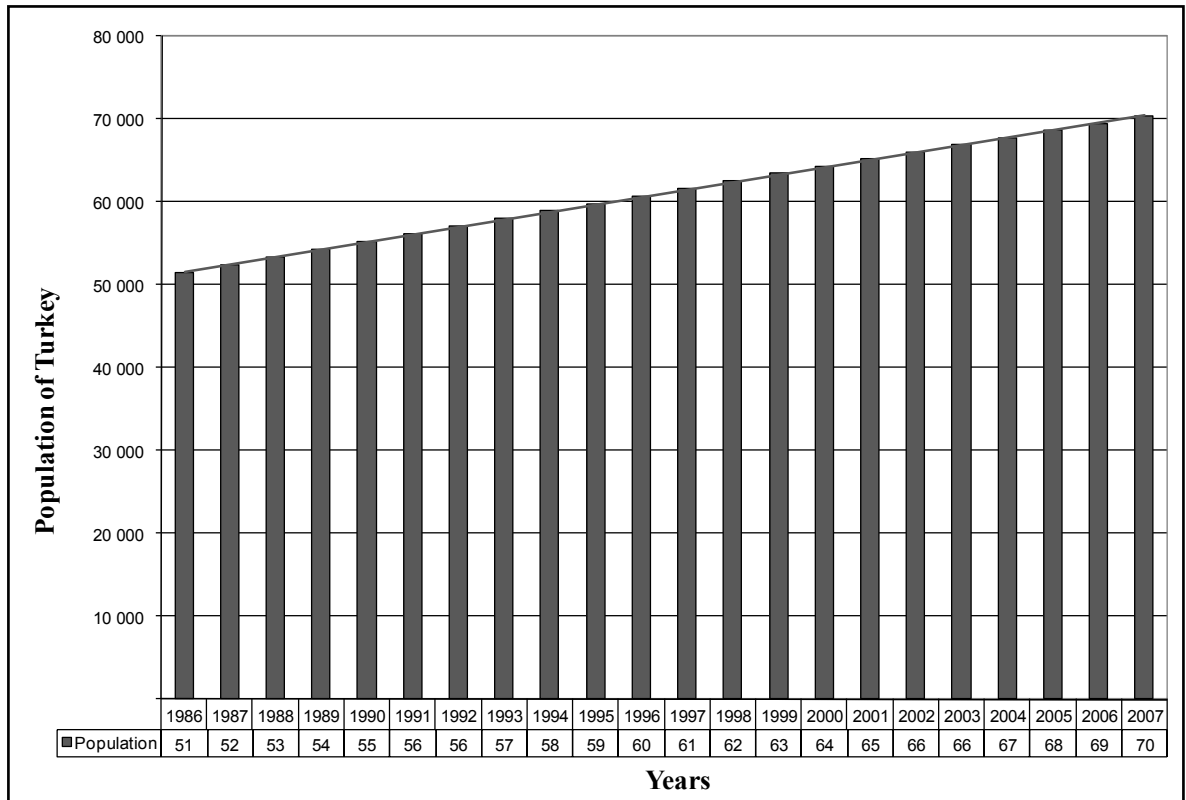


Figure 5.3. Population of Turkey in recent years (TUIK)

Another parameter which can also define the aircraft movements is number of commercial aircrafts registered in Turkey. More than 75 percent of the aircraft movements in Istanbul are carried out by the aircraft registered in Turkey<sup>3</sup>. Thus, trend of number of aircrafts is likely to be correlated with total number of aircraft movements. The trend in the past years is illustrated in Figure 5.4.

<sup>3</sup> Data is obtained from TUIK. Main source is DHMI.

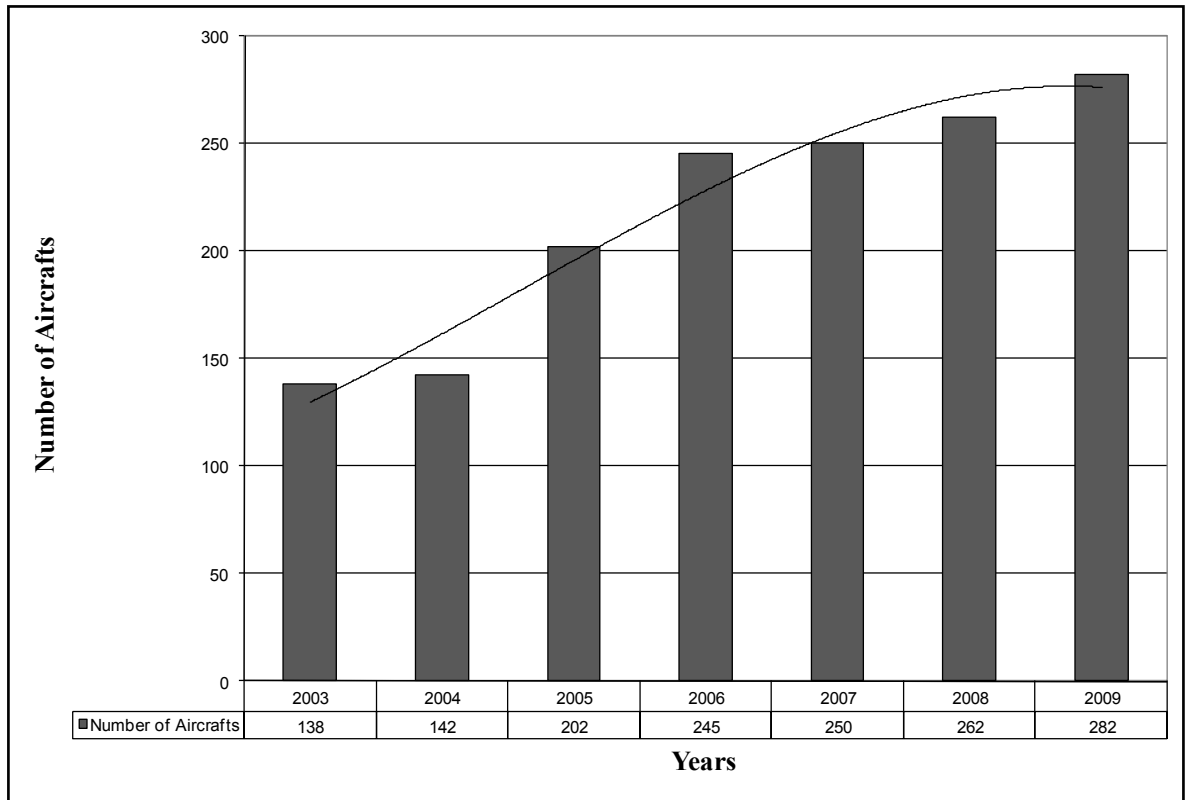


Figure 5.4. Number of Aircrafts registered in Turkey in recent years(DHMI)

The air fares and jet fuel prices have also crucial impact on aircraft movements. However, in the recent years, there have been significant fluctuations in the fuel prices and air fares. Therefore, it would not be wise to consider this parameter as an independent variable in constructing a regression model for aircraft movement model.

The correlation matrix between dependent variable, total aircraft movement and selected predictive variables; GDP per capita, population and total plane number was obtained by using the software SPSS, and presented in Table 5.1.

Table 5.1. Correlation Matrix for variables

Correlations					
		Total Aircraft Movement	Total Plane Number	GDP per Capita	Population
Total Aircraft Movement	Pearson Correlation	1	,974**	,985**	,996**
	Sig. (2-tailed)		0,001	0	0
	N	6	6	6	6
Total Plane Number	Pearson Correlation	,974**	1	,928**	,954**
	Sig. (2-tailed)	0,001		0,008	0,003
	N	6	6	6	6
GDP per Capita	Pearson Correlation	,985**	,928**	1	,995**
	Sig. (2-tailed)	0	0,008		0
	N	6	6	6	6
Population	Pearson Correlation	,996**	,954**	,995**	1
	Sig. (2-tailed)	0	0,003	0	
	N	6	6	6	6

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

It is clearly mentioned in the table, all independent variables are significantly correlated with independent variable and all have Pearson Correlation coefficient values which are very close to 1. Thus they all are capable of modeling the aircraft movement. However, they are also significantly correlated with each other. Therefore, we cannot construct a multiple regression model because of the multicollinearity problem. Instead, it is better to construct three different regression models for each independent variable and use them for demand forecasting.

### 5.2.2. Establishing Regression Models

In previous section, it is determined that the best way of modeling aircraft movement is creating three different models with independent variables; GDP per capita,

total aircraft number and population. The models are constructed by using SPSS. The results are tabulated in succeeding paragraphs.

The first model is constructed by having population as predictive variable. The graphical representation of model is illustrated in Figure 5.5.

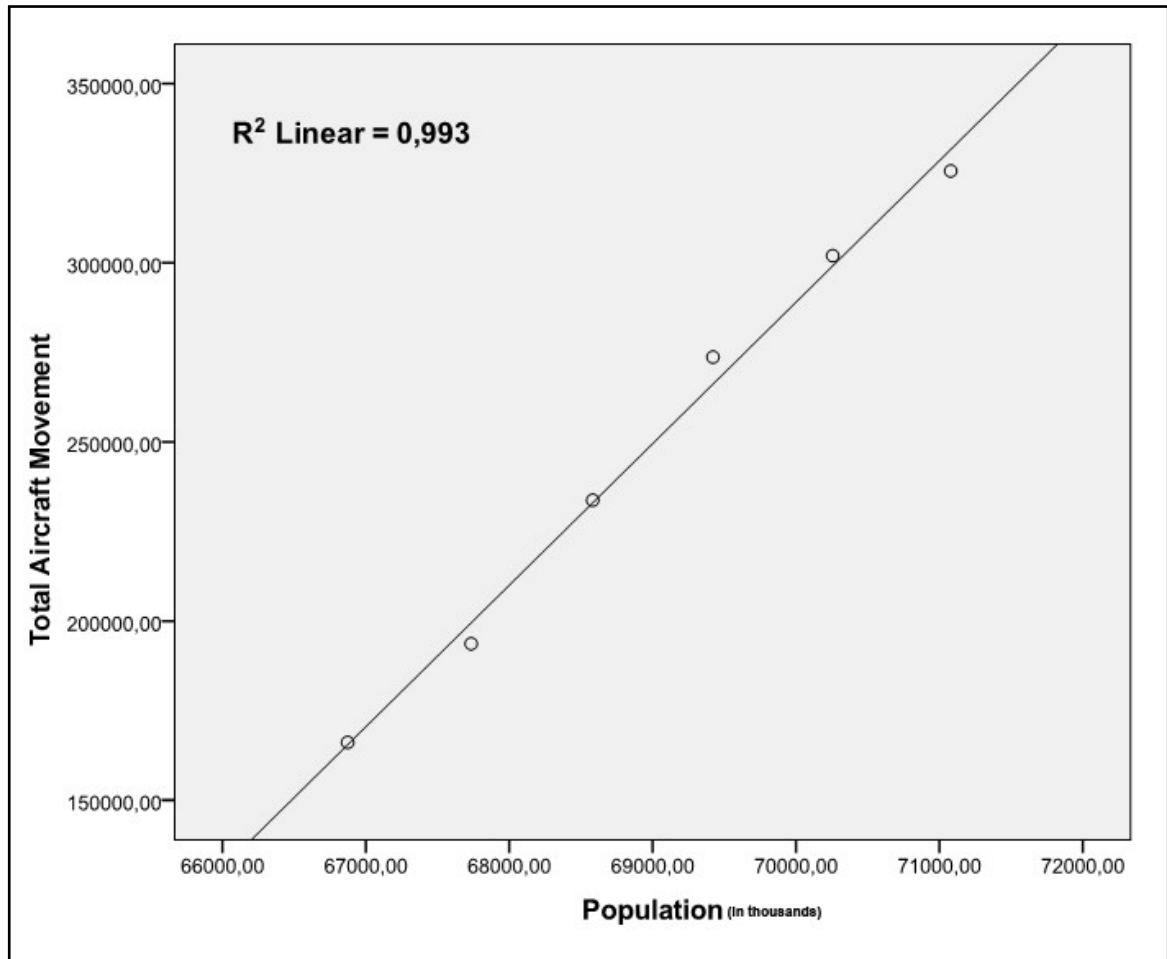


Figure 5.5. Regression Model for Aircraft Movement with Population

Moreover SPSS output table for model coefficient are given in Table 5.2 in below:

Table 5.2. Coefficients for Regression Model with Population

Coefficients <sup>a</sup>								
Model		Unstandardized Coefficients		Standardized Coefficients	t-value	Significance	R <sup>2</sup>	Overall F Value
		B	Std. Error	Beta				
1	(Constant)	-2476645,499	114361,661		-21,656	,000		
	Population	39,510	1,657	,996	23,840	,000	,993	568,347

a. Dependent Variable: Total Aircraft Movement

The model is significant, since R<sup>2</sup> value is close to 1 and represents the behavior sufficiently. After obtaining coefficients, the model equation can be constructed as shown in below:

$$T = -2,476,645.499 + 39.510 \times X_I \quad (5.1)$$

where,

T= Total Aircraft Movement

X<sub>I</sub> = Population (in thousands)

The second model shall be created by using GDP per Capita as an independent variable. As it is clearly shown in Figure 5.6, R<sup>2</sup> value of the model is 0.971 which is also very close to 1. Thus, this model is also statistically significant and a good representation of total aircraft movement.

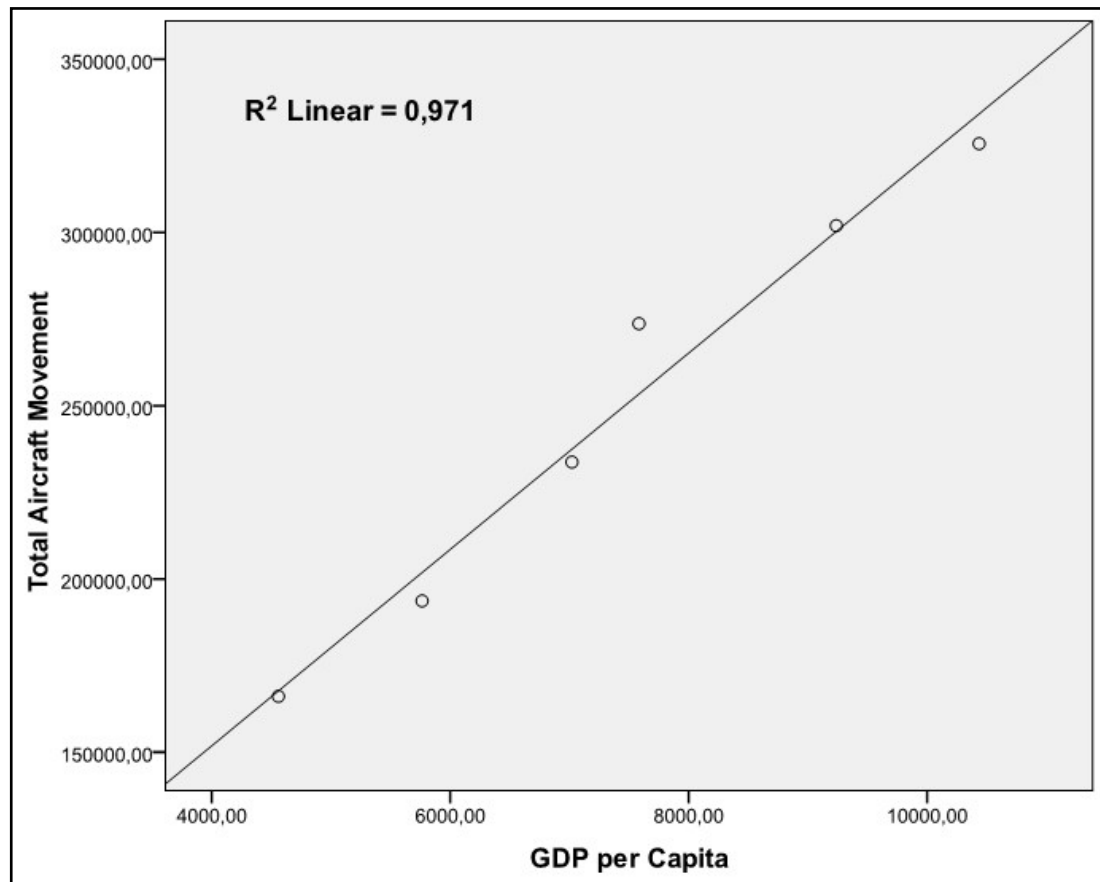


Figure 5.6. Regression Model for Aircraft Movement with GDP per capita

The model can be created from the SPSS output table given Table 5.3 in below.

Table 5.3. Coefficients for Regression Model with GDP per Capita

Coefficients <sup>a</sup>								
Model		Unstandardized Coefficients		Standardized Coefficients	t-value	Significance	R <sup>2</sup>	Overall F Value
		B	Std. Error	Beta				
1	(Constant)	38478,172	18969,291		2,028	,112		
	GDP per Capita	28,341	2,466	,985	11,493	,000	,971	132,090

a. Dependent Variable: Total Aircraft Movement

Subsequent to having the coefficients, the model equation is created as shown in below:

$$T = 38,478.172 + 28.341 \times X_2 \quad (5.2)$$

where,

T= Total Aircraft Movement,

$X_2$  = GDP per Capita

The final model is developed by utilizing total aircraft number as predictive variable. The plot of the model and  $R^2$  value are demonstrated in Figure 5.7.

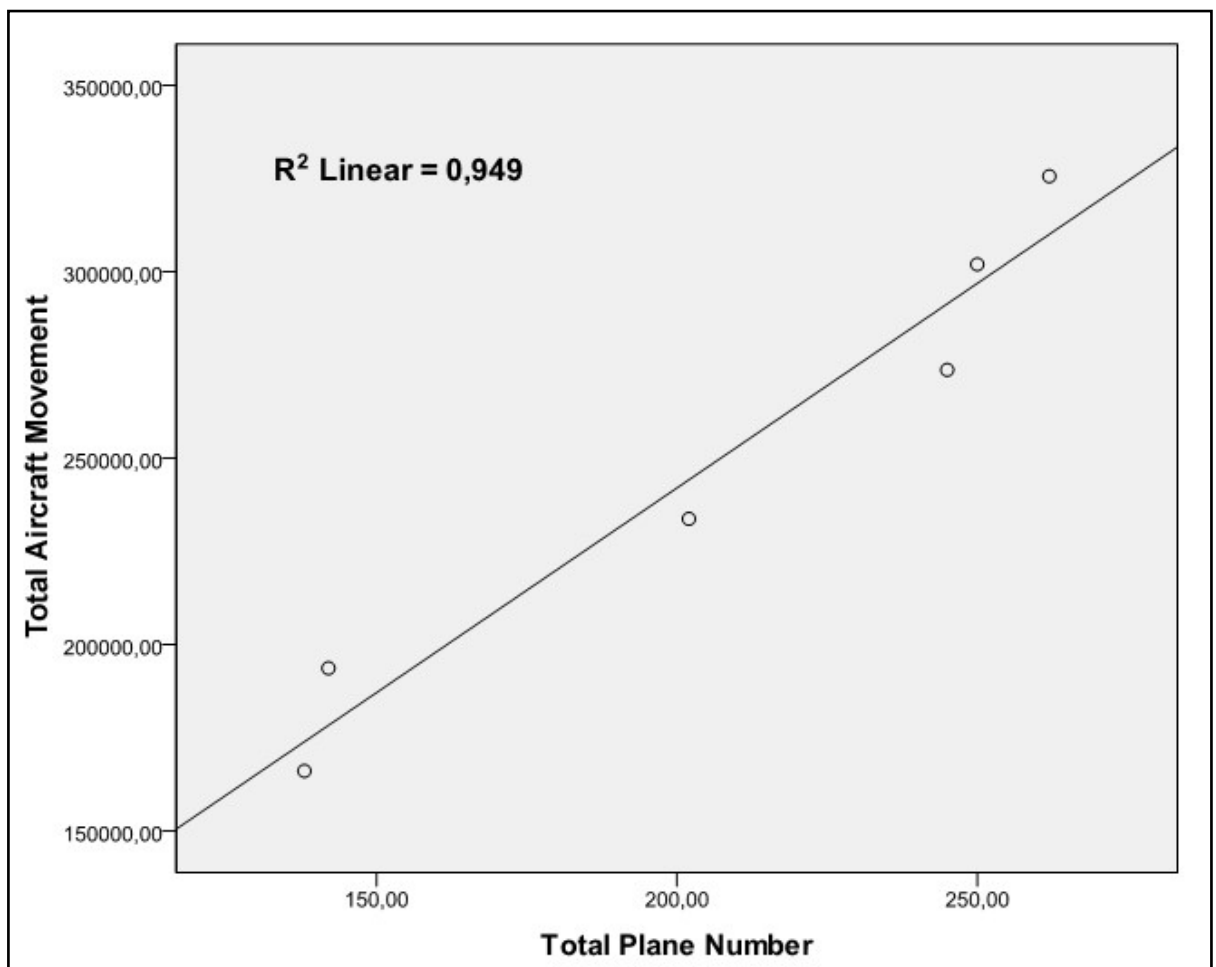


Figure 5.7. Regression Model for Aircraft Movement with Total Aircraft Number

The final model is also statistically significant, since  $R^2$  value is read from the figure as 0.949 which is very close to 1.

As a final step, the coefficients are extracted from SPSS and given in the Table 5.4 illustrated below:

Table 5.4. Coefficients for Regression Model with Total Aircraft Number

Coefficients <sup>a</sup>								
Model		Unstandardized Coefficients		Standardized Coefficients	t-value	Significance	$R^2$	Overall F Value
		B	Std. Error	Beta				
1	(Constant)	22470,216	26997,071		,832	,452		
	Total Aircraft Number	1097,724	126,988	,974	8,644	,001	74,724	,949

a. Dependent Variable: Total Aircraft Movement

Following to extracting the coefficients from SPSS, the model equation is created as shown in below:

$$T = 22,470.216 + 1097.724 \times X_3 \quad (5.3)$$

Where,

T= Total Aircraft Movement,

$X_3$  = Total Aircraft Number

Three statistically significant models were obtained for each independent variable as explained above. In the next section the predicted value of independents variables were acquired and plugged into the regression model equations in order to achieve forecasted value of total aircraft movements at the design year. The modal with the highest  $R^2$  value is the one that is obtained by the population variable. However, since all the models had very high  $R^2$  values, all three models were used to obtain demand forecast.

### 5.3. Forecasting the Aircraft Movement

In this section, the three models that were calibrated in the previous section were used for obtaining the forecast for the year 2024.

The first model was calibrated using the national population of Turkey. There are a variety of forecasts for Turkey's population. The most reliable one are the forecasts of governmental associates Turkish Statistical Institute (TUIK) and State Planning Organization (DPT). The forecast of TUIK for the population of Turkey for the year was 82,993,000 at 2024 (TUIK). We can obtain the forecast of aircraft movement at 2024 by inserting this value in to the equation 5.1 as shown below:

$$T = -2,476,645.499 + 39.510 \times 82,993 = 800,037 \text{ movements}$$

It can be summarized that according to the first regression model, the demand for aircraft movement will be approximately 800,000.

Secondly, the GDP per capita at 2024 shall be investigated. GDP was also predicted by various companies and governmental associations. In this thesis, the forecast carried out by Goldman Sachs and Koc Holding A.S. – Strategic Planning Department (2009) shall be utilized for estimating GDP per capita. The GDP value at 2024 is found 1475 billion USD. If this value is divided by total population estimate of TUIK given above, GDP per capita value can be calculated as mentioned below:

$$\text{GDP per capita} = 1475 \times 10^9 / 82,933 \times 10^3 = 17,785.4 \text{ USD}$$

Using the value in the regression model with GDP, the demand for 2024 can be calculated as given below:

$$T = 38,478.172 + 28.341 \times 17,785.4 = 542,535 \text{ movements}$$

It is very difficult to forecast GDP per capita in future years. Different sources can forecast considerably varying results. Thus, the forecasted value of aircraft movement by independent variable GDP per capita can also vary from the others models.

The final independent variable to be predicted is total number of aircrafts, in Turkey. Currently, there are 282 aircrafts and out of this number, 130 belongs to Turkish Airlines. The fleet of Turkish airlines will be expanded to 300-350 by the year 2023<sup>4</sup>. 105 additional aircrafts has already been ordered<sup>5</sup>. Moreover, Pegasus Airlines has 19 aircrafts and 24 orders are given and waiting for delivery<sup>6</sup>. All other companies have waiting orders and will expand their fleets in following years. By considering these figures above and making an extrapolation, it can be concluded that total number of aircrafts shall be around 600 in year 2024. If we insert this number into regression model equation 5.3, the last forecast for aircraft movement can be obtained as shown below.

$$T = 22,470.216 + 1097.724 * 600 = 681,105 \text{ movements}$$

Three different forecast values were obtained from each regression models. The reason for achieving different values depends on two main factors. First accuracies of prediction of independent variables are not the same. Second, the trends in the independent variables can change in longer terms. For example, effect of GDP per capita can show an exponential increase, and population may show a logarithmic trend in the longer periods. The average of these three models shall lead us sufficiently accurate forecast for total aircraft movement demand at 2024.

$$T_{\text{ave}} = (800,037 + 542,535 + 681,105) / 3 = 674,559 \text{ movements}$$

It can also be stated that total aircraft movement demand will be between 550,000 and 800,000 movements in year 2024. This number of aircraft movement is expected to create around 75-80 million passengers.

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<sup>4</sup> This number is given by Mr. Karlitekin ( Chairman of THY) in an interview.

<sup>5</sup> Information is obtained from Investor Relation Presentation (September 2009) of THY.

<sup>6</sup> This number is given by Mr. Sabanci ( Chairman of Pegasus Airlines) in an interview.

#### 5.4. Demand – Capacity Comparison and Results

In chapter 4, current runway capacities of both airports in Istanbul, Atatürk International Airport and Sabiha Gökçen International Airport, are calculated. It is determined that Atatürk International Airport currently has a capacity of 300,000 aircraft movements and 30 million passenger capacity which is composed of 20 million international and 10 million domestic passengers. However, currently Atatürk International airport has a capacity problem, even though total annual movement is approximately 280.000. Nevertheless, this problem can be solved with simple enhancements, such as; decreasing spacing time in arrivals and departures, implementing awareness campaign for all associated airlines and companies, at last but not least by slot coordination, but these enhancements shall be immediately implemented in order to solve only current capacity problems. In the future, with the increasing demand, these enhancements will not work out. With the help of these enhancements, the ongoing and prospected extension projects have been summarized in previous chapter and increase in the aircraft fleet mix, Atatürk International Airport is expected to have a capacity of 350,000-400,000 aircraft movements and 35-40 millions of passengers at 2024.

The other airport, Sabiha Gökçen International Airport is currently under utilized. Therefore, there is no capacity problem. The expected Annual Service Volume Capacity of Sabiha Gökçen International Airport at 2024 can be stated as 210,000 aircraft movements which may generate approximately 25,000,000 passengers. However, current capacity of terminals in Sabiha Gökçen International Airport is only 13,500,000 passengers. Therefore, it is necessary to construct a one more additional terminal in order to meet runway capacity and future demand. It is assumed that this new terminal will be constructed by the year 2024. With these analysis and assumptions summarized above, it can be stated that Istanbul airports shall be able to accommodate around 550,000-600,000 movements and 60-65 millions of passenger at 2024.

On the other hand it has been determined that the total aircraft movement demand at 2024 shall be 550,000-800,000 which will generate around 75-80 million passengers. All these results are summarized in the Table 5.5 given below:

Table 5.5. Summary of Demand – Capacity Relationship for Current and Year 2024

#	Description	Current		at 2024	
		Aircraft Movement	Passenger	Aircraft Movement	Passenger
1	Capacity of Istanbul International Airport	300.000	30.000.000	355.000	40.000.000
2	Capacity of Sabiha Gokcen International Airport	205.000	13.500.000	210.000	25.000.000
3	<b>Total Capacity of Istanbul Airports</b>	<b>505.000</b>	<b>43.500.000</b>	<b>565.000</b>	<b>65.000.000</b>
4	<b>Total Demand in Istanbul Airports</b>	<b>344.413</b>	<b>35.460.085</b>	<b>675.000</b>	<b>80.000.000</b>

It is very clear that, there will be capacity problem in future because of the increasing demand. In order to meet future demand, major enhancements are required. The best solution is surely addition of independent runway which will increase the total capacity and be sufficient to meet the future demand with reasonable investment cost. Addition of this runway to Atatürk International Airport would be the most feasible solution if the land around the airport would have permitted. Unfortunately, it seems impossible to construct independent runway which is 1035m away from the current runways. There is a potential area in Sabiha Gökçen Airport; however, this would not solve the capacity problem of Istanbul airports; since Sabiha Gökçen Airport is currently utilized under capacity, whereas Atatürk International Airport has capacity problems. The reason behind that can be identified as the weakness of Sabiha Gökçen Airport in competitiveness. Although those two airports are competing, Sabiha Gökçen Airport could not attract the passengers of Atatürk International Airport.

The last and most feasible option is to construct a new airport near to Atatürk International Airport. There is a proposed land Silivri, West Development Area of Istanbul, which shall be close to planned university, Techno Park, exhibition hall, cultural and congress halls. There is an area about 1000 hectares for new airport which can accommodate two 4km runways (IMP, 2008). The construction of new airport in Silivri will also have positive effect in development of this area and extend the Istanbul in west direction instead of north. This airport with two additional runways will generate around 300,000-350,000 additional aircraft movement capacity. The terminal building in this

airport can be designed to accommodate 40 million passengers to meet runway capacity. Moreover, this terminal building shall reflect the modernization of Turkey by being one of the biggest airports in the world.

The total aircraft movement capacity will reach to around 900,000 with the construction of above proposed airport. This capacity would be clearly sufficient to accommodate the demand in 2024. Moreover, it seems that these three airports will be capable of handling the demand till 2030s.

On the other hand construction of new runway in Sabiha Gökçen Airport shall be necessary in future when demand reaches the capacity in time. It would be better to construct this additional runway prior to this stage in order to prevent future delays and give a chance to compete with other airports according to the financial status. The area of this prospected runway has already been reserved in the southeastern part of the airport.

## 6. CONCLUSIONS & RECOMMENDATIONS

It is a challenging topic to monitor all necessities for airports and make a master plan for air traffic. In this study, the most important and restricting factor for development of airports and air traffic is determined and studied. It has been determined that runway capacity is the governing element of airport system. Other elements of airports, such as terminal capacity, stand capacity and land side interaction with surrounding environment are also studied by Eurocontrol, DHMI, DLH and IBB.

In this thesis, current runway capacities of the two airports in Istanbul, Atatürk International Airport and Sabiha Gökçen International Airport, were calculated. Then, the ongoing and prospected extension projects were summarized in order to estimate the capacity in design year of assessment (2024). It is determined that total capacity of Istanbul Airports will be between 550,000-800,000 aircraft movements and 60-65 million passengers.

The demand in year 2024 was forecasted to evaluate the sufficiency of the current capacity. Three statistically significant regression models were constructed by using three socioeconomic predictive variables, namely population, GDP per capita and number of aircrafts. Then these variables are predicted for the design year and the aircraft movement demand was forecasted using each of these models. The forecasted demand is expected to be between 550,000-800,000 aircraft movements which will create approximately 75-80 millions of passengers.


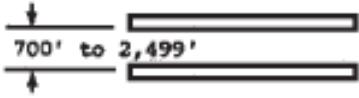
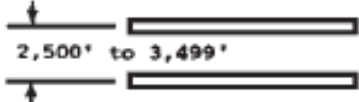
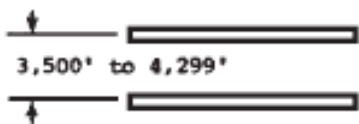
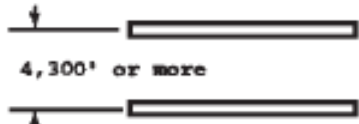
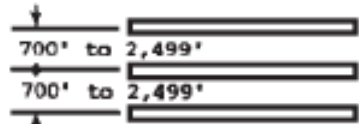
It was concluded that, the capacity will not be sufficient for the demand at 2024. Then, the remedies for this problem were summarized. It seems that there is a need for constructing a new airport and the site at Silivri as suggested by IMP (2009) seems to be a good choice. Moreover, the remedies of current capacity problems were also summarized.

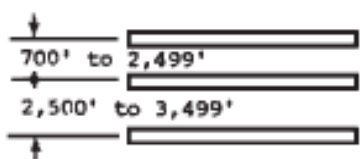
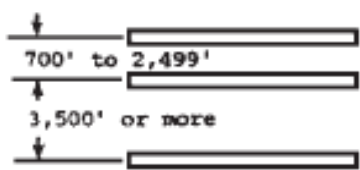
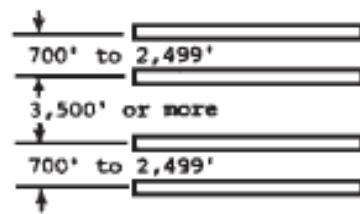
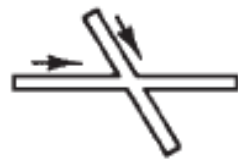
It is recommended that an additional passenger forecast with considering the developments in the aircrafts should be made. New large aircrafts (NLA), such as Airbus

A380, shall have passenger capacity of 500-800 (Barros and Wirasinghe, 1997). The airfield and the terminal building for proposed new airport should be planned accordingly to be able to provide necessary services for NLA`s. Additional refurbishments should also be performed in the existing airports in order to handle NLA`s.

In this study, only commercial passenger traffic was considered in the determination of the demand. Further studies should also be made for handling cargo.

## APPENDIX A: FAA CAPACITY ANALYSIS APPROXIMATION CHARTS

No.	Runway Configuration Diagram	Mix Index-- Percent (C+3D)	Hourly Capacity (operations per hour)		Annual Service Volume (operations per year)
			VFR	IFR	
1.		0 to 20	98	59	230,000
		21 to 50	74	57	195,000
		51 to 80	63	56	205,000
		81 to 120	55	53	210,000
		121 to 180	51	50	240,000
2.		0 to 20	197	59	355,000
		21 to 50	145	57	275,000
		51 to 80	121	56	260,000
		81 to 120	105	59	285,000
		121 to 180	94	60	340,000
3.		0 to 20	197	62	355,000
		21 to 50	149	63	285,000
		51 to 80	126	65	275,000
		81 to 120	111	70	300,000
		121 to 180	103	75	365,000
4.		0 to 20	197	62	355,000
		21 to 50	149	63	285,000
		51 to 80	126	65	275,000
		81 to 120	111	70	300,000
		121 to 180	103	75	365,000
5.		0 to 20	197	119	370,000
		21 to 50	149	114	320,000
		51 to 80	126	111	305,000
		81 to 120	111	105	315,000
		121 to 180	103	99	370,000
6.		0 to 20	295	62	385,000
		21 to 50	213	63	305,000
		51 to 80	171	65	285,000
		81 to 120	149	70	310,000
		121 to 180	129	75	375,000

No.	Runway Configuration Diagram	Mix Index-- Percent (C+3D)	Hourly Capacity (operations per hour)		Annual Service Volume (operations per year)
			VFR	IFR	
7.		0 to 20 21 to 50 51 to 80 81 to 120 121 to 180	295 219 184 161 146	62 63 65 70 75	385,000 310,000 290,000 315,000 385,000
8.		0 to 20 21 to 50 51 to 80 81 to 120 121 to 180	295 219 184 161 146	119 114 111 117 120	625,000 475,000 455,000 510,000 645,000
9.		0 to 20 21 to 50 51 to 80 81 to 120 121 to 180	394 290 242 210 189	119 114 111 117 120	715,000 550,000 515,000 565,000 675,000
10.		0 to 20 21 to 50 51 to 80 81 to 120 121 to 180	98 77 77 76 72	59 57 56 59 60	230,000 200,000 215,000 225,000 265,000
NOTE: → Denotes predominant direction of runway operation.					

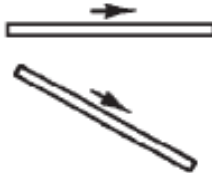
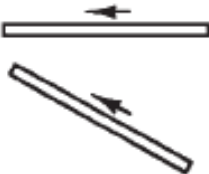
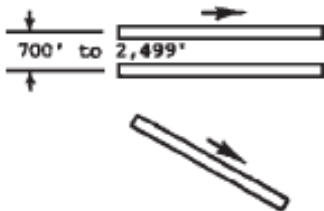
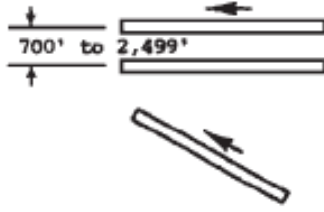


No.	Runway Configuration Diagram	Mix Index-- Percent (C+3D)	Hourly Capacity (operations per hour)		Annual Service Volume (operations per year)
			VFR	IFR	
11.		0 to 20 21 to 50 51 to 80 81 to 120 121 to 180	197 145 121 105 94	59 57 56 59 60	355,000 275,000 260,000 285,000 340,000
12.		0 to 20 21 to 50 51 to 80 81 to 120 121 to 180	197 149 126 111 103	62 63 65 70 75	355,000 285,000 275,000 300,000 365,000
13.		0 to 20 21 to 50 51 to 80 81 to 120 121 to 180	197 149 126 111 103	62 63 65 70 75	355,000 285,000 275,000 300,000 365,000
14.		0 to 20 21 to 50 51 to 80 81 to 120 121 to 180	197 149 126 111 103	119 114 111 105 99	370,000 320,000 305,000 315,000 370,000
NOTE: → Denotes predominant direction of runway operation.					

No.	Runway Configuration Diagram	Mix Index-- Percent (C+3D)	Hourly Capacity (operations per hour)		Annual Service Volume (operations per year)
			VFR	IFR	
15.		0 to 20	197	59	355,000
		21 to 50	147	57	275,000
		51 to 80	145	56	270,000
		81 to 120	138	59	295,000
		121 to 180	125	60	350,000
16.		0 to 20	150	59	270,000
		21 to 50	108	57	225,000
		51 to 80	85	56	220,000
		81 to 120	77	59	225,000
		121 to 180	73	60	265,000
17.		0 to 20	132	59	260,000
		21 to 50	99	57	220,000
		51 to 80	82	56	215,000
		81 to 120	77	59	225,000
		121 to 180	73	60	265,000
18.		0 to 20	295	59	385,000
		21 to 50	210	57	305,000
		51 to 80	164	56	275,000
		81 to 120	146	59	300,000
		121 to 180	129	60	355,000
NOTE: → Denotes predominant direction of runway operation.					

No.	Runway Configuration Diagram	Mix Index-- Percent (C+3D)	Hourly Capacity (operations per hour)		Annual Service Volume (operations per year)
			VFR	IFR	
19.		0 to 20	197	59	355,000
		21 to 50	145	57	275,000
		51 to 80	121	56	260,000
		81 to 120	105	59	285,000
		121 to 180	94	60	340,000
20.		0 to 20	301	59	385,000
		21 to 50	210	57	305,000
		51 to 80	164	56	275,000
		81 to 120	146	59	300,000
		121 to 180	129	60	355,000
21.		0 to 20	264	59	375,000
		21 to 50	193	57	295,000
		51 to 80	158	56	275,000
		81 to 120	146	59	300,000
		121 to 180	129	60	355,000

NOTE: → Denotes predominant direction of runway operation.

No.	Runway Configuration Diagram	Mix Index-- Percent (C+3D)	Hourly Capacity (operations per hour)		Annual Service Volume (operations per year)
			VFR	IFR	
22.		0 to 20	150	59	270,000
		21 to 50	108	57	225,000
		51 to 80	85	56	220,000
		81 to 120	77	59	225,000
		121 to 180	73	60	265,000
23.		0 to 20	132	59	260,000
		21 to 50	99	57	220,000
		51 to 80	82	56	215,000
		81 to 120	77	59	225,000
		121 to 180	73	60	265,000
24.		0 to 20	295	59	385,000
		21 to 50	210	57	305,000
		51 to 80	164	56	275,000
		81 to 120	146	59	300,000
		121 to 180	129	60	355,000
25.		0 to 20	197	59	355,000
		21 to 50	145	57	275,000
		51 to 80	121	56	260,000
		81 to 120	105	59	285,000
		121 to 180	96	60	340,000
NOTE: → Denotes predominant direction of runway operation.					

No.	Runway Configuration Diagram	Mix Index-- Percent (C+3D)	Hourly Capacity (operations per hour)		Annual Service Volume (operations per year)
			VFR	IFR	
26.		0 to 20	301	59	385,000
		21 to 50	210	57	305,000
		51 to 80	164	56	275,000
		81 to 120	146	59	300,000
		121 to 180	129	60	355,000
27.		0 to 20	264	59	375,000
		21 to 50	193	57	295,000
		51 to 80	158	56	275,000
		81 to 120	146	59	300,000
		121 to 180	129	60	355,000
NOTE: → Denotes predominant direction of runway operation.					
SPECIAL NOTE:					
(1) The configurations shown above do not include layouts with more than two runway orientations. Therefore, for those airports with runway configurations involving three or more orientations, it is necessary to identify the runways in the <u>two</u> orientations used most frequently.					
(2) Missed approach protection is assumed for converging operations in IFR conditions.					
(3) Multiple arrival streams are only permitted on parallel runways.					

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