Economics of the Airport Capacity System in the Growing Demand of Air Traffic – A Global View

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Abstract

Economic prosperity brings greater demand for travel. As people get wealthier, they can afford to travel further and more often. In the case of aviation this trend has been amplified by technological advances, cost efficiencies and strengthened competition within the industry, which have brought air travel within the reach of many million people. In an era of increasing globalization, foreign travel - whether for pleasure or on business - is now a common experience. The increasing affordability of air travel has opened up new destinations and possibilities. Further, it has also expanded people's horizons, opportunities and expectations. As a result, air travel has shown a three-fold increase over the last 30 years.

The availability of sufficient airport capacity is an important constraint on future growth. However, even at current levels of use, many airports in the U.S., Europe and few airports in Asia Pacific are becoming increasingly congested as they attempt to cope with rising passenger numbers. In some cases, the capacity of terminals and runways is at, or near, saturation point.

Key words: Airside / Landside Capacity, Congestion, Delays, Pricing, Short-Term & Long Term Planning

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Introduction

Air transportation industry has climbed to an important stage and has been one of the fastest growing industries in the regional, national and global level. The average annual growth of air passenger and freight traffic was showing an increase of 4.0 per cent and 5.0 per cent respectively during the last one decade. However, the economic and political interruptions (11th September) have temporarily destabilized and slowed down the air traffic growth. Nevertheless, recovery was seen after one year and the air transport planners assessed that the air traffic would grow tremendously for the next two decades by forecasting the demand, which demonstrates that the average growth would be 4-5% for passengers and freight transport by 5.5-6.5% globally. Among the other region, Asia Pacific is projected to be high growth region in the world during the next 10 years (ACI, ICAO & IATA, 2005).

The growth of air transport has produced number of advantages on economic and social impacts at the local and global scale. The first and foremost is generating employment opportunities directly and indirectly and this stimulated the regional and global economy. Air transportation helps in integrating different regions for cultural co-ordination to attain social progress. Further it helps in environmental protection by prudent use of natural resources. The economic regulation of international air transport is going through a dynamic change as a result of increasing competition, trans-nationalization of business, globalization of the world economy and the emergence of regional economic groups, privatization and liberalization of service industries. In this scenario, the increasing air traffic demand reveals the shortage of airport infrastructure capacity as the crucial one. In particular, some of the matured air transport regions/ markets in US, Europe and some regions in the Asia pacific, the airport capacity has been affected by different operational, economic and environmental constraints, which have started to act as "Blockage" in impeding the future growth of airports and air traffic demand.

Methodology and Objectives

This paper deals with different concepts of airport capacity, which appear due to dominance of the particular constraints. In addition, the paper discusses the problem of long term matching airport capacity to growing demand by analyzing the case of UK, US and some of the developing airports in the Asia Pacific regions. The paper consists of five sections, which clearly depict on the following-

Section-1 Introduction
Section-2 Importance of Airport and Components of an Airport System
Section-3 Concepts of Airport Capacity and their constraints
Section-4 Case study of UK, US and some developing Airports in Asia Pacific regions
Section-5 Conclusion

The data used in the study are secondary data from various studies done by air transport planners, Federal Aviation Administration, ICAO, IATA and Airport Council International. This is theoretical based analyzed study. The major objective of the study is to highlight the constraints of airport capacity and their disadvantages in the growing globalized economy.

Importance of Airport Infrastructure and Components of Airport System

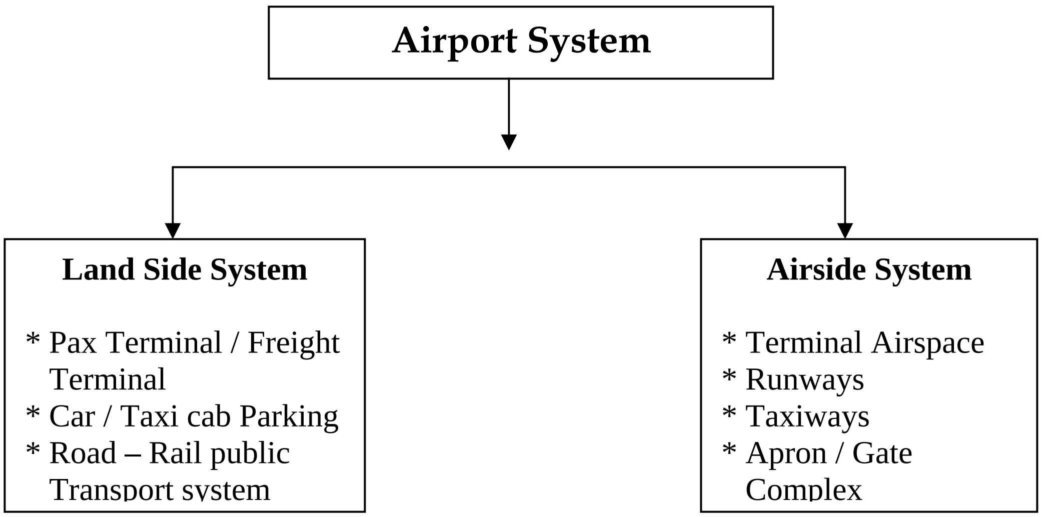
Airports are acting as nodal centres and they are sine qua non for the air transport sectors. Its networks facilitate the local and regional economy to function smooth and effervescent by involving multitude of distribution and exchange input to business competitiveness and efficiency. In the current market driven economy, airports are viewed as a "Powerful Engine" for regional and national economic development by establishing a major centre for business, commercial and industrial activity. Good airport network link provides the potential towards the success of national productivity, tourism penetration, trade, and foreign direct investments and often consummate by improved technology and innovation.

Modern airport network management theory reveal airport as a "Multi-Modal Business Centre". The development of successful airports helps in encouraging the formation of clusters of industries. Further the most important contribution of airports is generating millions of employment opportunities worldwide. In the present world environment, airport is a showcase of cultural, economic and technological achievements of the nation.

Airport helps in providing facilities to Aircraft, Passenger and Freights to meet the air travel demand by means of building up of an airport and air cargo terminal in the regions.

Airport System

An airport system consists of two components for the smooth function of airport operational services to the travelling public and user communities. It has been described in the flow chart below-



Landside System

Landside system embraces surface access systems, which is connecting to an airport to its catchment area, passenger and freight terminal system (Ashford et al 1997, Janic 2001). The surface access system embraces individual car, taxicab, rail and road based public transport systems. These facilities are provided for transport outgoing and incoming passenger, airport employees and visitors to and from the airport. The airport passenger and freight terminal system consists of two components dedicated interfaces and passenger (and freight) terminals, which both enable transfer of passengers (and freight) between the airport surface transport systems and aircraft and vice versa (Ashford et al., 1997).

Airside System

The airport airside system consists of airspace around airport called the ‘Airport Zone’ or ‘Terminal Airspace’, runways, taxiways and apron / gate complex. The airspace provides accommodation for the arrival of aircraft just before landing and the departure aircraft just after taking-off. The runway accommodates the ground phase of landing and taking-off. Taxiways physically link the runway and apron / gate complex and enable the aircraft for taxing between two complexes. At apron / gate complex, the aircraft perform their ground handling services (Ashford et al., 1997; Janic, 2001).

Airport Operational Capacity and its Corresponding Demand

The infrastructure capacity is one of the most important parameter in determining the operational and planning of an airport. There are various concepts of capacity exists, which are distinguished in reliance with dominant factors impeding the capacity. Broadly, there can be operational, economic and environmental factors (Caves and Gosling, 1999; Janic, 2001a). Generally, these may function together, but in majority of the cases only one factor dominates and determines the airport capacity. To understand the concepts first let us outline the basic meaning of capacity and their elements in bottlenecking the capacity problems at the airport.

Capacity refers to the ability of an airport to handle a given volume or magnitude of traffic (demand) within a specific period of time. In other words, the operational capacity is generally expressed by the maximum number of units of demand that can be accommodated at an airport during given period of time and under given conditions. Capacity measures can be done on Maximum Throughput Rate (MTR) and Level of Service (LOS) related capacity. MTR is defined as the 'average number of demands a server can process per unit of time when always busy'. In empirical notion

$$\mu = 1/E\ (t)$$

Where
μ = Maximum Throughput Rate
E (t) = Expected service time

Level of service (LOS) related capacity is measured through the number of demands processed per unit of time while meeting some pre-specified LOS standards (must know μ to compute).

Airport Capacity Categorization

Airport capacity planning is categorized into four types, namely –

- Theoretical Capacity
- Potential Capacity
- Practical Capacity &
- Operational Capacity

Theoretical Capacity is defined as ' the maximum number of aircraft that the airport is able to process per unit of time without considering the quality of services'.
Potential Capacity is defined as ' the maximum number of aircraft that the airport is able to process per unit of time for given levels of demand (arrivals)'.

Practical Capacity is defined as ‘ the maximum number of aircraft which can be processed per unit of time for a given mean delay level’.

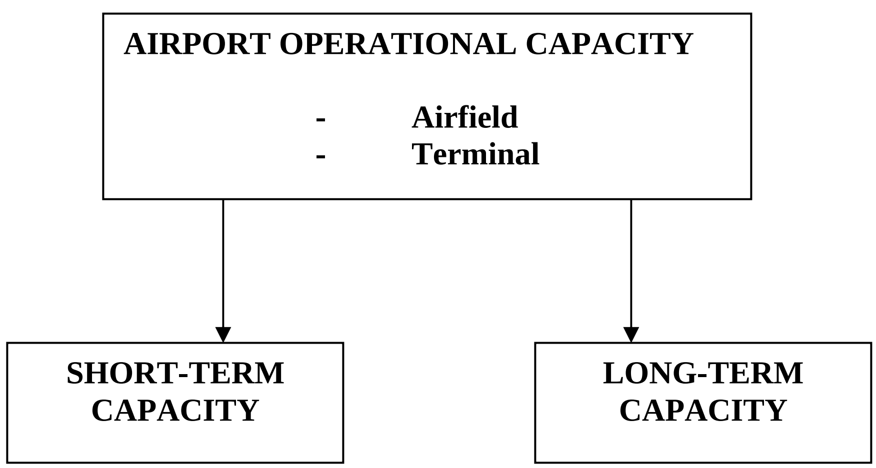
Operational Capacity is defined as ‘ the maximum number of aircraft which can be processed per unit of time for a given maximum delay’.

Ops Cap ≤ Pra Cap ≤ Pot Cap ≤ The Cap

The units of demand are the air transport (Aircraft Movements, Passengers and Freight shipments). Accordingly, to analyze and investigate the airport operational capacity, four elements have to be seen, viz.,

- Airspace
- Airfield
- Terminal &
- Ground Access

Based on these four elements airport operational capacity is determined according to the time scope. The operational capacity is segregated into two periods, namely - short term and long term as an operational and planning parameter in estimating the capacity of an airport.



Airfield Operational Capacity

The capacity of an airfield is primarily function of the major aircraft operating surfaces, which encompasses of the facility and the configuration of those surfaces (Runways & Taxiways). However, it is also related to wind coverage, airspace utilization, the availability and type of navigational aids. Climatological conditions influence the layout of the airfield and also impact the use of the runway system. Variations in the weather resulting in limited cloud ceilings and reduced visibility typically lower airfield capacity, while change in wind direction and velocity typically dictate the runway usage and also influence runway capacity.

Ceiling and Visibility: Airport capacity and delay describes three categories of ceiling and visibility minimum for use in both the capacity and delay calculations. They are-

- Visual Flight Rules (VFR)
- Instrumental Flight Rules (IFR)
- Poor Visibility & Ceiling (PVC)

Based on these parameters, the airfield operational capacity is calculated through short-term and long-term capacities.

Short-Term Capacity

In the short-term, the operational capacity is determined for given period of time, say one hour and for given conditions. The 'constant demand' for service and the average delay per customer defines the conditions, and thus the concept of 'Ultimate or Actual' and 'Practical or Declared' is derived (Janic, 2001).

a) *Ultimate or Actual Capacity*

The constant demand, which is related to the concept of ultimate or actual capacity, entails that an airport or its elements is constantly busy during given period of time (one hour). In an airport airside area the relevant units for expressing capacity are the aircraft movements – (Arrival & Departure). In the airport landside areas are passengers and freight shipments. To determine the ultimate capacity, number of factors is influenced in the airport airside; they are the number and configuration of runways, aircraft separation rules, mix of arrivals and departures and their time pattern, which may read out the operational strategies for carrying out different operations and the aircraft fleet structure (Gilbo, 1993; Janic, 2001; Newell, 1979).

b) Practical or Declared Capacity

The airport 'practical' or 'declared' capacity relates the maximum number of aircraft movements accommodated at an airport during the given period of time, i.e., one hour based on the ceiling and visibility condition of an airport and the average delay imposed on each of them while being served. Actually, the number of units of demand served during one hour at which the average delay is guaranteed to each unit of demand determines the airport 'practical' or 'declared' capacity.

Theoretical relationships between the average delay per air traffic movement and the airport practical capacity reveals the delay due to eccentricity in arrival of aircraft and fluctuations of their service times (CAA, 1993; Horonjeff & McKelvey, 1994; Janic, 2001; Newell, 1979). The eccentricity of arrival increases the average time delay with direct increase in the demand / capacity ratio. For example, the major airport airside capacity is given in the Table –1 below.

Table – 1

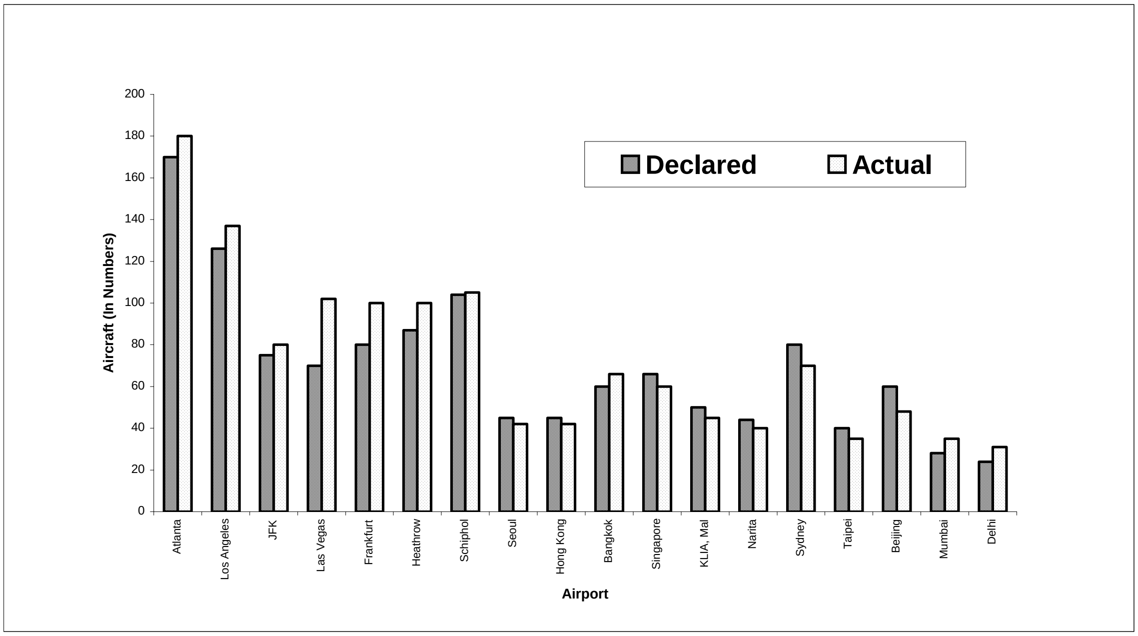
Major Airports Airfield (Runway) Capacity – Short Term Capacity

AIRPORT	AIRPORT SCALE	DECLARED VFR CAPACITY	DECLARED IFR CAPACITY
Atlanta	Large	170	180
Los Angeles	Large	126	137
JFK	Large	75	80
Las Vegas	Large	70	102
Frankfurt	Large	80	100
Heathrow	Large	87	100
Schiphol	Large	104	105
Seoul	Medium	45	51
Hong Kong	Medium	45	42
Bangkok	Medium	60	66
Singapore	Medium	66	60
KLIA, Mal	Medium	50	45
Narita	Medium	44	40
Sydney	Medium	80	70
Taipei	Medium	40	35
Beijing	Medium	60	42
Mumbai	Medium	28	32
Delhi	Medium	24	31

Source- FAA, IATA, ATAG & ACI 2003

Figure- 1

Major Airport Airfield Operational Capacity



Factors Constraining Airside Capacity

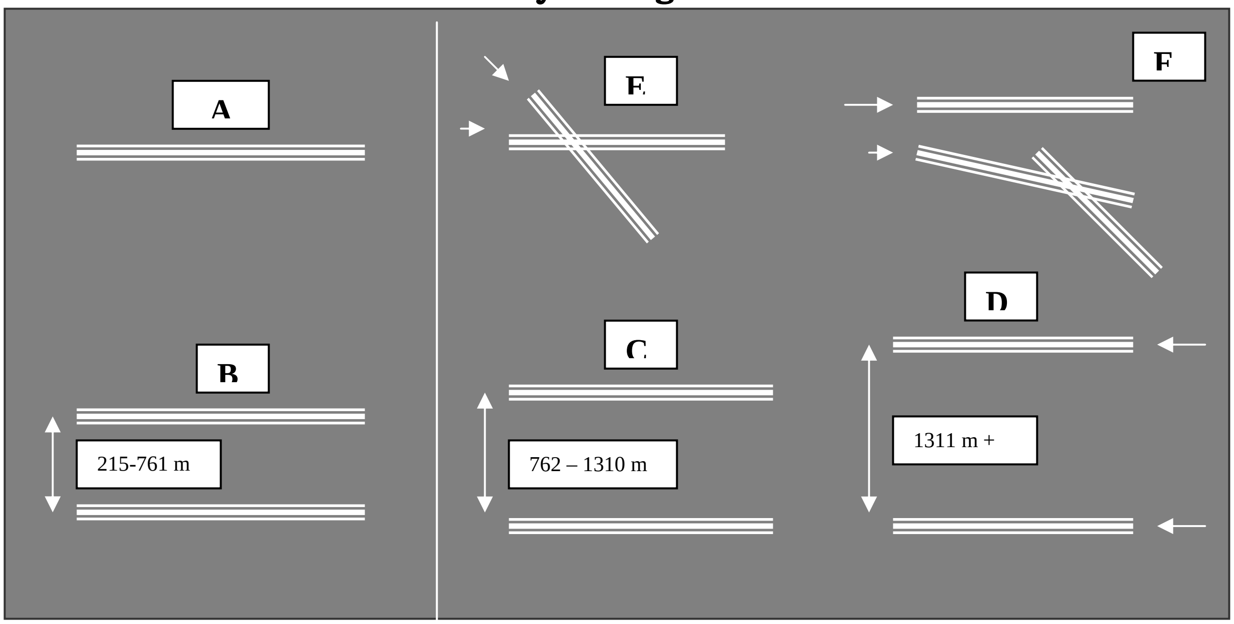
There are various factors affecting the airport airside capacity, namely

- Number of Layout of Active Runways
- Separation Requirement (Longitudinal, Lateral)
- Weather condition (Ceiling, Visibility)
- Wind (Direction & Strength)
- Mix of Aircraft
- Mix and Sequencing of operations (Landings, Takeoffs, Mixed)
- Quality and Performance of ATM System (including human factor – Pilots & Controllers)
- Runway Exit locations
- Noise considerations

Airfield (Runway) Configuration

The capacity of an airport depends on the number of runways available and their interactions. For instance, for a given traffic mix a particular runway can handle 65 operations an hour in VFR conditions and 55 in IFR weather. The VFR capacity of two parallel runways should be 2500 feet apart, and then it will have 125 operations per hour – twice the capacity of a single runway. Yet the IFR capacity of this two-run way system would be more like 65 operations per hour, because under IFR conditions runways are less than 4300 feet apart considered 'dependent' for purposes of landings, i.e., an operation on one prevents a simultaneous operation on the other. Thus, not only is the capacity of each runway reduced during bad weather, but also the capacity of the airport is further reduced because not all runways may be fully used.

Figure – 2
Runway Configuration



Source - ICAO Airport Planning Manual, 1987

Runway Classification	Hourly Capacity – (Ops / Per hour)		Annual Volume Ops/ Per hour
	VFR	IFR	
A	51-98	50-59	195000-240000
B	94-197	56-60	260000-355000
C	103-197	62-75	275000-365000
D	103-197	99-119	305000-370000
E	72-98	56-60	200000-265000
F	73-150	56-60	220000-270000

In the above figure, these runways are used in several different ways. Each of these combinations may have a different operating capacity, and each might be suitable for different set of wind, visibility and traffic conditions. A large-scale airport like Chicago O'Hare might have 40 or 50 possible combinations of runway uses. The limitation imposed by the available runway system varies among the top air carrier airports. Chicago O'Hare airport has seven runways; Kennedy has five runways.

Air Traffic Control Equipments and Procedures

ATC Equipments and procedures is also one of the factor impeding airport capacity constraints. Improvements in aircraft surveillance, navigational and communication equipment over the past decade have greatly increased the ability of pilots and controllers to maintain high capacity during all weather conditions. However, there are still ATC-related limits on airport capacity. Clearance used in the en route airways and the terminal airspace is frequently circuitous, routing aircraft through intermediate fixes or control points rather than allowing them to travel directly.

Aircraft Mix

Aircraft mix (characteristics) also hinders the airside capacity. Aircraft size, aerodynamics, propulsion and braking performance and avionics affect the capacity of the runways they use. Pilot training, experience and skill also influence performance and the capacity of a runway can vary greatly with the types of aircraft using it. Runway capacity is usually highest if the traffic mix is uniformly small, slow, propeller-driven aircraft. Where the traffic mix is highly diverse – with varying sizes and speeds, it is difficult to maintain optimum spacing and optimum runway usage, which in turn reduces the capacity. The direction of traffic also affects runway system capacity.

Weather Constraints

Heavy fog, snow, strong winds, or icy runway surfaces shrink the airport's ability to accommodate aircraft and may even close an airport completely. For any given set of weather conditions, several of the different runways configurations available at an airport may be suitable but only one will have the maximum value. Using these maximum values, and plotting them with the percentage of the year during which different weather conditions are likely to prevail, a 'capacity coverage curve' for any given airport can be constructed. Therefore, airport hourly capacity varies strongly with weather conditions. There is a 3:1 or 2:1 ratio between good weather / bad weather capacities.

Wake Vortex

Aircraft mix (characteristics) performance creates the problem of wake vortexes. This also obstructs the airport airside capacity. Aircraft passing through the air generate coherent energetic air movements forms the wakes, and quiescent weather conditions for 2 minutes (120 seconds) or even longer after an aircraft passes. The strength of the vortex increases with the weight of the aircraft generating it. As the case of wide-bodied aircraft (B-747, DC-10) become more common in the early 1970's, it became apparent that wake vortexes behind these aircraft were very strong enough to endanger the following aircraft, especially a smaller aircraft. In order to prevent wake vortex accidents, FAA increased the separations for smaller aircraft behind larger ones during weather conditions when persistent vortexes may be a danger. These minimum separations are shown below in the table.

Table – 2
Arrival & Departure Separations

Minimum Arrival Separations – Nautical Miles

Visual Flight Rules*

Trail / Lead	S	L	H
S	1.9	1.9	1.9
L	2.7	1.9	1.9
H	4.5	3.6	2.7

Instrument Flight Rules

Trail / Lead	S	L	H
S	3	3	3
L	4	3	3
H	6	5	4

Minimum Departure Separations – Seconds

Visual Flight Rules*

Trail / Lead	S	L	H
S	35	45	50
L	50	60	60
H	120	120	90

Instrument Flight Rules

Trail / Lead	S	L	H
S	60	60	60
L	60	60	60
H	120	120	90

* VFR Separations are not operational minima but rather reflect what field Data show under saturated conditions
The above table is adapted from Parameters of Future ATC Systems Relating to Airport Capacity / Delay (Washington D.C: FAA)

Long Term Capacity

The concept of long-term ultimate capacity assumes that the fully developed single runway airport can operate at an average rate of ‘ **x** ‘ per hour. If daily operations time would be ‘ **y** ‘ hours per day during **365** days per year, then the total airside capacity would be ‘ **z** ‘ (that is the total aircraft movements per annum). In empirical notions

$$Z = x * y * 365$$

Where

“Z” is Total Aircraft Movements per Annum
“x” is Average rate of aircraft movements per Hour
“y” is Airport Operational Timings

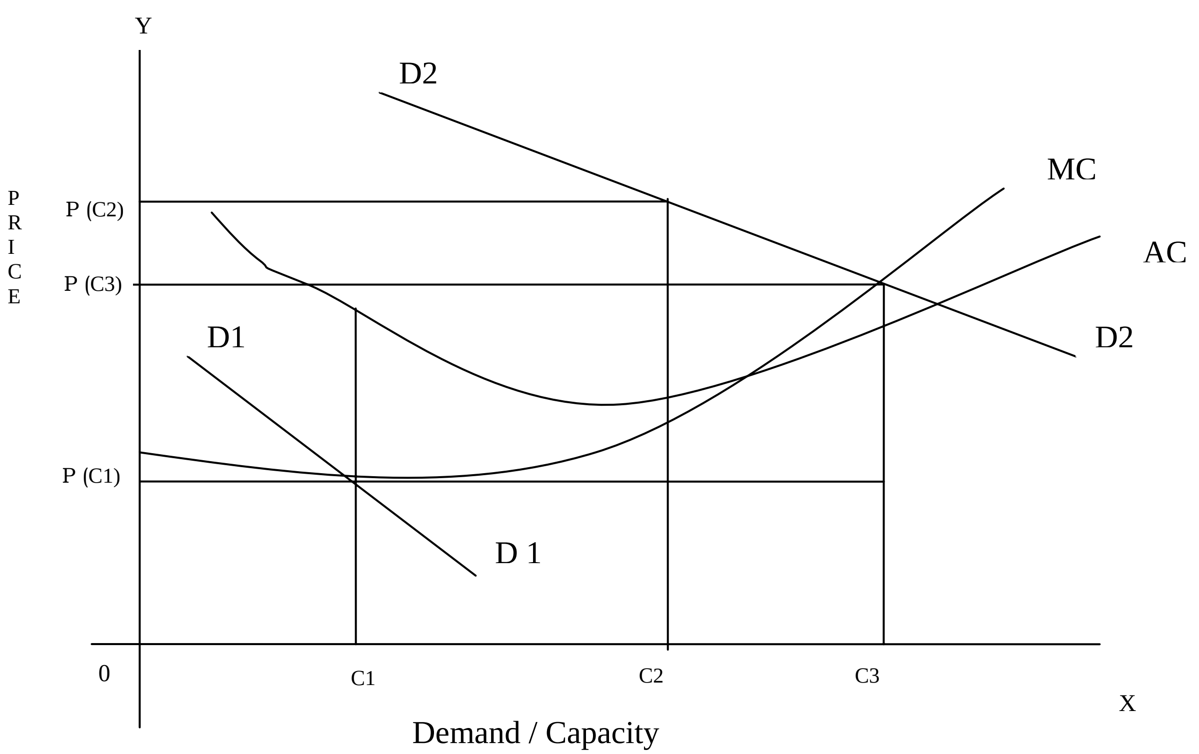
The annual capacity of a single runway airport configuration could surpass 195000 operations with suitable taxiways, apron and air traffic control facilities (ICAO, 1987). However, the development of an additional runway based on capacity requirements may be considered for airports with a current demand level below 150000, if traffic is increasing. Besides, the capacity requirements, importance of the airport to the community it serves may warrant an additional runway to avoid any insurgency. Annual aircraft movements have close correlation with the total annual number of passengers. At 60 biggest European airports, air traffic movements and passenger have a strong dependence on the annual number of passengers (ACI Europe, 2001).

Airport Economic Capacity

The airport economic capacity is defined by the economic conditions, which may significantly influence the number of units of demand accommodated at an airport in both short and long term, during a given period of time (one hour or per year). In the short-term, the charges of an airport services during the peak and off-peak hours determine the economic conditions. This set up is maintained to balance between demands and supply (capacity) under given market conditions (regulation). In, general, the charges reflects airport operating costs on the one side and on the other side, characteristics of demand in terms of type of users and their willingness to pay for services.

Principles of Charging Airport Services

The charging of airport service is under the principle of marginal cost pricing on two circumstances, viz., (Peak period & Off-Peak period). During the off-peaks, demand is low, and the corresponding price is also low to maintain this demand. In the peak period, the demands for airport services are high and accordingly the price during this period is also high. However, in the former case the MC is lower than the AC, and thus the corresponding price produces losses for the airport operators. In the second case, the situation is opposite and the price is equal to the MC and thus brings earnings to the airport operator (Doganis, 2002; Faweett & Faweett, 1998).



The objective of such pricing policy has two fold:

- To cover the airport operating costs and
- To regulate the intensity of access of demand

If such number of aircraft movements (and consequently the passengers) is lower that achieved under the operational (safety) constraints, the economic capacity is considered as a relevant (Janic, 2001a).

In the long-term, the availability of investments for an airport expansion principally determines the economic conditions, and thus the airport long-term economic capacity. In general, if there is no investment in an airport infrastructure – the new runway(s) or terminal (s), existing airport capacity cannot be expanded in order to match the long term growing demand (Caves & Gosling, 1999).

Principles behind Long-Term Matching the Airport Capacity to Demand

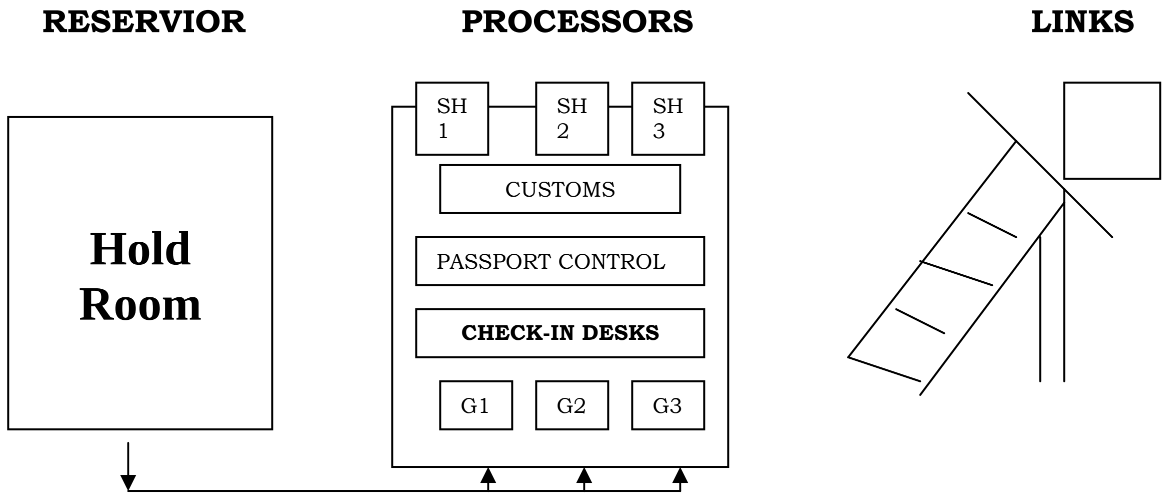
There are two ways to cart out corresponding airport capacity and demand. Firstly, it may be an increased utilization of existing capacity by using the innovative operational procedures and new technologies. However, this option is very limited domain (Little, 2000). Secondly, the option includes building the new infrastructure. It takes place from time to time and consists of adding the relatively large portions of the infrastructure capacity to the airport airside and landside area (new runway, terminal and apron).

Land Side Constraints

Aircraft delay in arrival and departure form a critical problem in the airport landside area. Congestion at the airport terminal buildings, access roads, and parking areas increasingly threatens the capability of airports to serve additional passengers and air cargo. Measuring the capacity of airport landside facilities and services is becoming critical issue. Since the layout of passenger buildings are associated with runways, taxiways, apron, car parks and access roads. Airport airside has a close relationship with airport landside. Both are interdependent with each other in accommodating aircraft and passenger, which in turn demonstrating the airport capability. Today most of the airports in US, UK and few airports in Asia Pacific is facing crisis in the landside capability due to zooming traffic.

Airport Terminal

Airport terminals are building according to the runway capacity, aircraft parking stands and number of gates available for processing the passenger to board the aircraft. Airport terminal capacity is based on the scale of airport (large, medium & small). Pedestrian flow in the terminal building is composed of enplane and deplane passengers process and visitors. The terminals are accessible to both occupants (Departure & Arrival) with various in which they pass through various sub-systems. The sub-system is categorized into three, viz., Reservoirs, Processors and Links.



<u>*Reservoirs*</u> – Reservoirs are waiting or queuing area (hold rooms)

<u>*Processors*</u> – Processors comprise various processing area (X-Ray Baggage, Check-in-area, Regulatory (Passport Control or Immigration, Customs & Security)

<u>*Link*</u> – Links allow for the movement of occupants from one sub-system to another (Corridors, Escalators)

There are three primary measures to estimate the sub-systems capacity, namely – Static capacity, Dynamic capacity and Sustained capacity. These capacities measure the terminal building to know the number of passenger during a given period of time.

<u>***Static Capacity***</u> – static capacity is used to portray the storage potential of a facility or area, and it is usually expressed in terms of number of occupants in a given area at any one moments. It is a function of the total useable space available and the level of service to be provided. Hence, the capacity is measured by the following methods:

Static capacity – Usable Area (m2) / Space standard (m2 /Occ)

Static capacity standards are stated as square meters per occupant for each level of services. A time factor may also be included against the lower, more critical levels, which allows brief surges of congestion to be acceptable during peak periods.

<u>***Dynamic Capacity***</u> – Dynamic capacity refers to the maximum processing or flow rate of persons (occupants) through a sub-system per unit of time.

The actual time unit is selected as the measurement index (Minutes and Hours) depends on the nature of the operation.

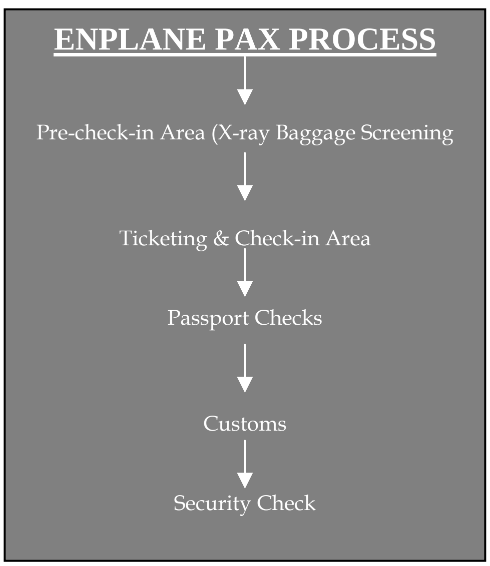
Dynamic capacity = Individual server processing rate X Number of servers
(Passenger/Time unit) (Passengers / Time unit / Server)

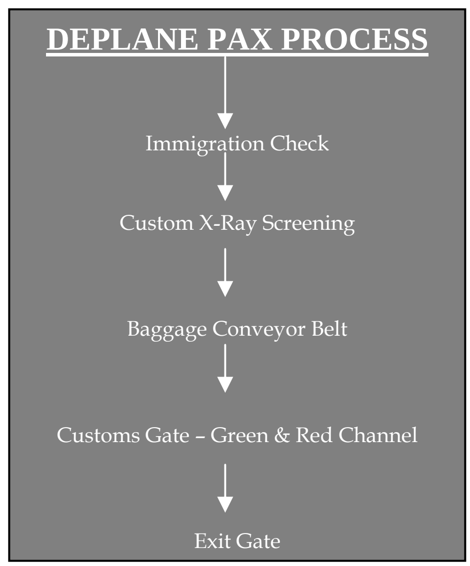
The processing rates can be based on observation or standards, and should take into account such variables as flight sector, personnel performance, automation etc.

Sustained Capacity – Sustained capacity is used to describe the overall capacity of a sub-system to accommodate traffic demand over a sustained period within the space and time standards of a particular level of service. It is thus a measure of the combined dynamic and static capacities of the processors, reservoirs and links.

Terminal Building Pax Flows

Enplane and Deplane sub-system processes are used to determine the terminal building passenger flows and their capacity. These can be explained by the flow chart below –





Based on these parameters airport terminal capacity is calculated and lastly we define the scale of airport with passenger holding capacity per hour and annum. The scale or size of airport is used to analyze the measure of production in terms of physical output of passenger flow or passenger holding during given period of time. Airport scale is defined as 'capacity ***of producing (accommodating) the physical output (Pax) in airport terminal operation'***. Unlike, other industries, the airport infrastructure is also categorized into three scale units of production, viz,

Airport Scale	Per Annum	Per Hour Holding	Airport
LARGE SCALE AIRPORT	70-80 MPA	7000-9000PH	ATLANTA
MEDIUM SCALE AIRPORT	10-39 MPA	1000-4000PH	SINGAPORE
SMALL SCALE AIRPORT	1 – 9 MPA	200-1000PH	SRI LANKA

MPA – Million Passengers per Annum
PH - Passengers per Hour (in Numbers)

Case Study of US, UK and Asia Pacific Airports

United States (US) and European Airports Capacity Holding

Pigou was the first economist to study about transport infrastructure congestion and delays in the road transport and later the modern literature was shaped and developed by Walter (1961) and Vickrey (1963). Today, air transport infrastructure is facing a serious problem worldwide; some regions like US and European countries are tremendously impacting the growth of demand. For example, the US and European major airports flight arrival caused delayed more than 15 minutes and 30 minutes approximately (Salant, 2001 and Janie, 2003). Further, the study done by ATAG, estimated that economic loss during the congestion and delays costs approximately 6.0 Billion and 6.5 billion US $ in US and European countries (ATAG, 2003). Delaying B-747 with engines running for one minute per hour costs the world economy $ 1 million a lost productivity as passengers sit and wait at any given time, 500 jets are idling (John Wensween, 2000). The major reason for congestion and delay are due to –

- An imbalance between air transport demand and infrastructure capacity management and
- Unplanned disruption of airline schedules

Demand is represented by the flight schedule at an airport carried out by one or more airlines. At many large European and U.S hub and non-hub airports one or few airlines carry the flight operations based on slots allocated to them with considering airport declared (practical) capacity to get the service of that airport. In the US and European region airports, capacity is determined under given conditions. In European countries, the airport runway capacity is measured in terms of IMC (Instrumental Meteorological

Conditions) and IFR (Instrumental Flight Rules). Usually, this capacity is an agreed value between airlines, airports and air traffic control (EUROCONTROL, 2002). In the US, the airport capacity is determined under two values; namely the higher under VMC (Visual Meteorological Conditions) and VFR (Visual Flight Rules), and the lower under IMC and IFR (FAA, 2001).

Many large airports in U.S and European regions are slot controlled, because, this can help to balance the number of flights with the airport declared capacity in order to control the congestion and flight delays under certain benchmarking boundaries. At these airports, the initial demand and the available airport capacity are balanced through the multi-stage process of negotiations between airlines, airports and air traffic control. In such framework, the demand is generally exceeding the level of airport capacity over the long period and enables planned congestion and delays. However, due to the system imperfectness and other disrupting factors, the actual demand exceeds the declared supply and as a result this roots unpredictably longer congestions and delays. To show an example, Atlanta's Hartsfield Airport is taken for analyses which is depicted below (Figure-1)

Figure – 1

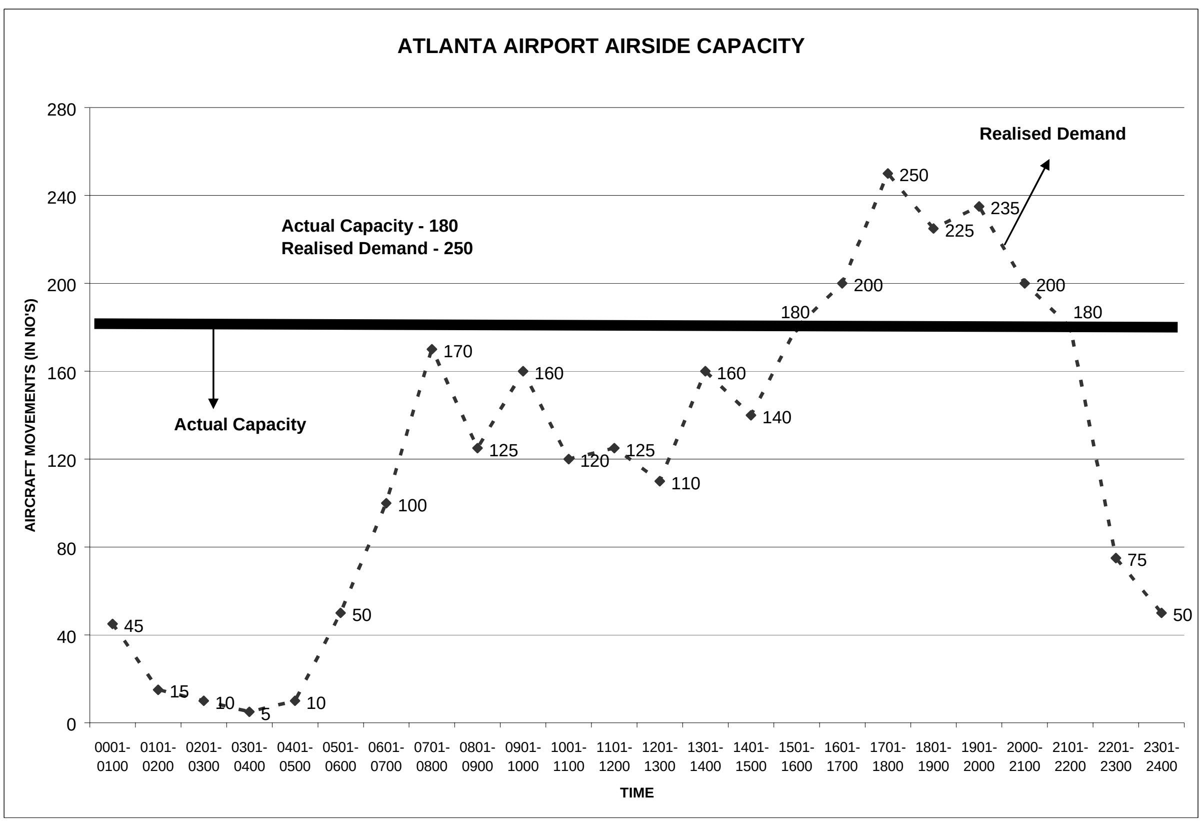


Figure 1 illustrates the relationship between demand and capacity at the U.S Atlanta Hartsfield Airport. Atlanta Hartsfield Airport is the largest and the top of the first 100 airports in the world. It accommodates 70-80 Million passengers per annum. This airport handles approximately 250-275 flights per hour. Airport demand varies from one airport to another, due to its importance and its proximity. The pattern of air traffic demand is quiet different at Atlanta airport due to hub-and-spoke operations of the main Delta Airlines. The above figure reveals that the morning and afternoon hours the realized demand has been less than the actual capacity. However, it exceeded the capacity considerably during the late afternoon and evening hours. This clearly indicates the relationship between demand and capacities imply congestion. However, this congestion is of the distinctive nature. In some airports like New York's La Guardia Airport, congestion and flight delays occurs due to competing airlines and used airport as "Origin" and "Destination" of their flights. In the terminal side, the airport handles approximately 8000 – 9000 passengers per hour.

European Airports – London Heathrow Airport

Heathrow airport is serving as "Origin" and "Destination" and also acting as a carrier's hub-and-spoke network in the recent years. So, the demand is a mixture of both in terms of business and leisure passengers. It has been the hub of the biggest national (UK) scheduled carriers British Airways. The airport handles approximately 63.0 million passenger and 0.5 million aircraft movements per annum. Airside capacity at Heathrow airport varies from 82 – 100 aircraft movements per hour (EUROCOTROL, 2001). The airport handles higher than the declared runway capacity and terminal capacity. To overcome this impact, Terminal-5 is on the completing card in order to sustain the growing demand of air traffic in the region. In the European region, airport congestion and delay are comparatively low as compared to U.S airports.

Congestions and Delays

Congestion causes flight delay. In simple term, delay is defined as "***the difference between the actual and scheduled time at the referent location***". The threshold for either arrival or departure flight delay is the period longer than 15 minutes behind the schedule (AEA, 2001; BTS, 2001; EUROCONTROL, 2001; FAA, 2002). Congestion and delay have become common phenomenon at many airports in Europe and U.S. To substantiate this study, let us reveal the study done by Milan Janic (2004), which highlights some of the major airports at these two regions (U.S and Europe). It is found that, in Europe, the flight delays varied between 17% and 30% for arrivals and from 8% to 24% for departures. On the contrary, in the U.S., this proportion has varied between 22% and 40% for arrivals and from 19% to 38% for departures. By seeing these two regions, we can conclude that, in general, more frequent delays have taken place at the U.S than European airports. Table –3 would show some relevant statistics of delays at the two regions.

Table- 3

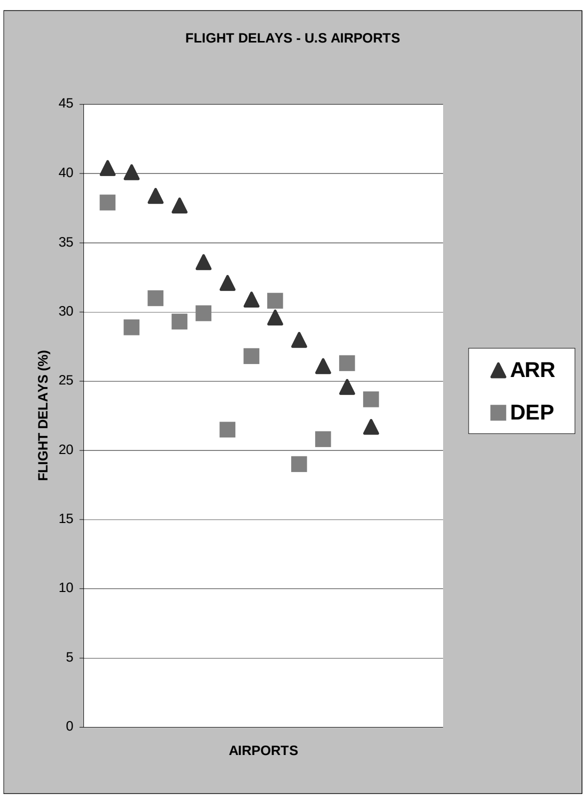
Delays at some congested European and U.S. Airports

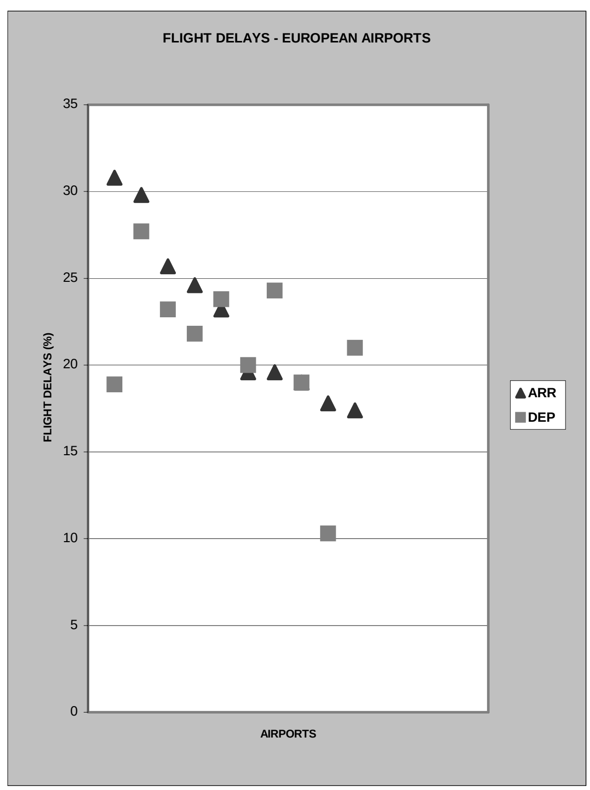
U.S. AIRPORTS	% OF FLIGHTS DELAYED		EUROPEAN AIRPORTS	% OF FLIGHTS DELAYED	
	Arrivals	Departure		Arrivals	Departures
Philadelphia	40.4	37.9	Frankfurt	30.8	18.9
NY- La Guardia	40.1	28.9	Brussels	29.8	27.7
Newark	38.4	31.0	Amsterdam	25.7	23.2
Boston Logan	37.7	29.3	Paris – CDG	24.6	21.8
Chicago- O'Hare	33.6	29.9	Zurich	23.2	23.8
San Francisco	32.1	21.5	Madrid	19.6	20.0
Atlanta	30.9	26.8	London Gatwick	19.6	24.3
Phoenix	29.6	30.8	Munich	19.0	19.0
NY-JFK	28.0	19.0	Copenhagen	17.8	10.3
Los Angeles	26.1	20.8	London Heathrow	17.4	21.0
Detroit	24.6	26.3			
Dallas – Ft. Worth	21.7	23.7			

Source – EUROCONTROL / ECAC, 2002; FAA, 2002

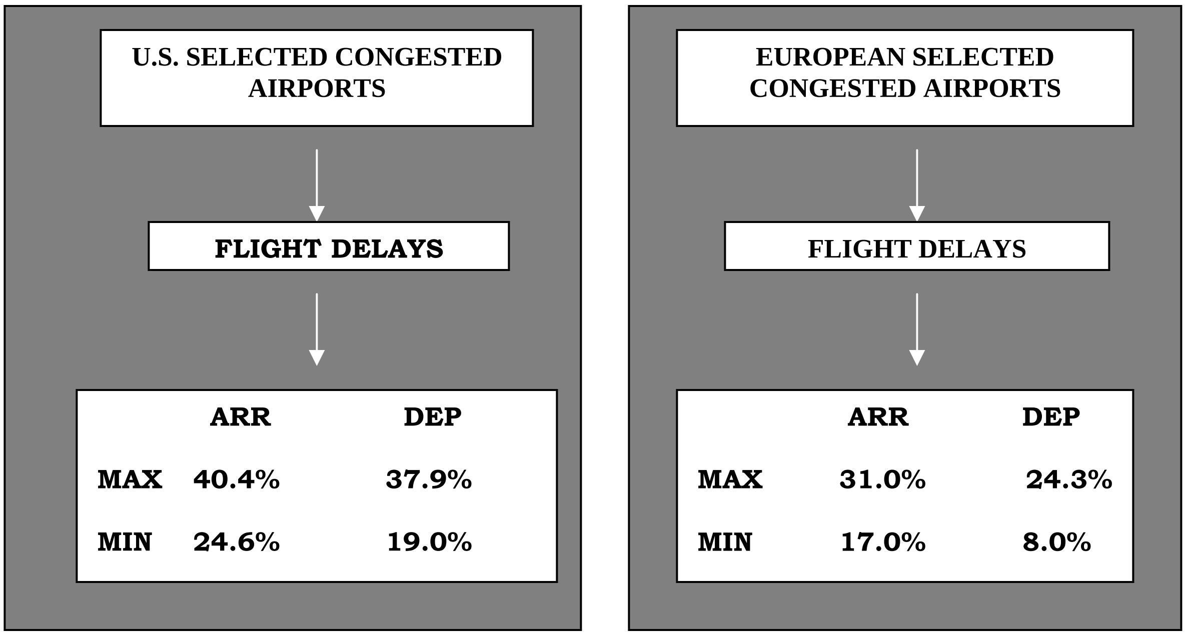
Figure – 2

Flight Delays in Percentage





Delays at airports are commonly articulated as the average time per flight or the average time per delayed flight (the total delay divided by the number of all or by the number of only delayed flights per period) (EUROCONTROL / ECAC, 2002; FAA, 2002). In addition, total delays are constantly segregated into the arrival and departure. Figure –2 clearly indicates the percentage of delays of aircraft (Arrival and Departure) at the two regions selected airports. The study found out the maximum and minimum delay at the selected congested airports of U.S. and Europe regions.



Source: FAA, 2002 Source: EUROCONTROL/ECAC, 2002

It is also revealed that the average delay per flight – either departure or arrival, has been generally longer at the U.S than European airports. At European airports, there has not been any conspicuous difference between the average delay per arrival and departure flight. Almost all delays have been shorter than 10 minutes. In the U.S. airports, the departure delays are higher than the arrival delays. It is varying between 10 and 20 minutes in the departure and in the arrival, the delay varies between 5 and 15 minutes (Janic, 2004). Generally, the threshold of 15 minutes is adjustable and should not be considered delayed at all. In the U.S., on an average of 70-75% flight delays are caused by weather and congestion about 20-30% of these delays (BTS, 2001; FAA, 2001; 2002). In Europe, on an average, 1-4% flight delays are caused by weather and congestion about 30-40% of these delays (AEA, 2001; EUROCONTROL, 2001).

Quantification of Congestion Costs

Congestion costs can be empirically appraised with flight delays, by computing total extra time spent by passengers and airlines, and using some assumptions on the value of time for passengers and cost for airlines. X done a study on congestion cost at one of the European airport (Madrid Airport) with the help of actual number of passengers at each flight is known, the type of aircraft providing the service, which allows applying differentiated hourly rates per aircraft to evaluate airlines' congestion costs.

Table –4
Passenger Congestion Costs: Total cost & Average cost

	JULY 1997	**JULY 1998**	**JULY 1999**	**JULY 2000**
Total Cost (in Million €) – Total Monthly costs				
Arrivals	6.42	7.39	8.71	8.84
Departure	7.94	7.64	8.60	7.34
Total Flights	**14.36**	**15.03**	**17.31**	**16.18**
Average Cost (in € / passenger) – Per Pax				
Arrivals	4.04	4.36	4.51	4.01
Departure	4.91	5.89	5.95	4.53
Total Flights	**4.49**	**5.02**	**5.14**	**4.24**

Source – Madrid Airport Financial Statistics, 2001

Table-5
Airlines Congestion Costs (in Million €)

	July 1997	July 1998	July 1999	July 2000
Arrivals	14.7	16.7	20.3	22.0
Departures	18.0	17.6	20.4	17.2
Total Flights	32.7	34.3	40.7	39.2

Passenger congestion costs reveal the magnitude of the problem facing at Madrid Airport. In July 2000, total passenger costs amounted to 16.2 million €. Average costs are estimated between 4.5 – 5.0 € per passenger. The process of airport expansion induced some reductions in the average cost per passenger obtained in 2000 compared to previous years. Adding congestion costs borne by passengers and airlines, the significant of the problem of congestion experienced at Madrid airport can be assessed. Taking July 2000 as a month of reference, total congestion costs in 2000 amounted to 55.4 million € (Pax costs + Airlines Costs). In annual terms, assuming that July could be considered a representative month of the activity of Madrid airport, total congestion costs are evaluated to 664.8 million €.

Case study of Asia Pacific Airports

Asia Pacific region is now driving the world's economic growth including aviation sector, with Singapore, Thailand, Vietnam, China and India leading a centre stage and going to occupy the prominent share in the aviation growth. Asia pacific region share has gone up in the world aviation market during the last one decade. The prospective market for air transport has exposed cryptogram of a sturdy global resurgence, with Asia Pacific region's performance far exceeding the world average growth during the next one decade. Governments in Asia have been spending huge investments on national carriers and there is a sign of ploughing private sector investments into private airlines. Asia Pacific region traffic has zoomed to 760.90 million from 615.70 million in 2000, with an average growth of 6.0% approximately. By, 2014, the region will touch 1.0 billion passengers and above travelling to and from and within Asia Pacific. The regions share of total international scheduled passenger traffic will be touching 36.0% by 2014, primarily as a result of trade expansion and liberalization and globalization policies.

Trade normalization and market liberalization would help China and India to achieve the highest growth as compared to other countries in the Asia Pacific region. China will become the largest Asia Pacific country for domestic and international scheduled passenger followed by India, Japan, Vietnam and other countries. The most rapid growth has been seen in the Europe-Asia Pacific and Trans Pacific traffic. The current globalization trends have encouraged airlines to intensify hubbing activities at major airports in the Asia Pacific. During the last 10 years, significant progress has been made in the airport and air space development to enhance growing demand. Accordingly, the region has started building "New Brand Airports" at Hong Kong, Kula Lumpur, Shanghai, Seoul, Bangkok, Beijing, Tokyo – Narita and Osaka Kansai airport. Other countries like Singapore, Indonesia, Philippines and India are also expanding the terminal to accommodate the growing traffic in the region. The Table below would show the declared capacity of airside and terminal at the respective airports as on 2002

AIRPORT	RUNWAY	TERMINAL	STATE/COUNTRY	REGION
Bangkok	60	10500	Thailand	Asia Pacific
Peking	60	9200	Beijing, China	Asia Pacific
Hong Kong	50	9000	China	Asia Pacific
Lahore	30	1200	Pakistan	Asia Pacific
Kula Lumpur	50	7100	Malaysia	Asia Pacific
Mumbai	24	5000	India	Asia Pacific
Delhi	24	3500	India	Asia Pacific
Gimpo Seoul	32	-	S.Korea	Asia Pacific
Changi	66	19000	Singapore	Asia Pacific
Kingsford	80	7200	Sydney	Asia Pacific
Taipei	50	12000	Taiwan	Asia Pacific
Narita	44	16000	New Tokyo	Asia Pacific

Proliferation of Low-cost Airlines in Asia

Many Asian countries have under gone transformations in which suddenly in the last one year, the number of airlines has multiplied. Singapore has three low cost airlines (Jet Star, Tiger Airways and Valuair), which launched their operations in 2004. Indonesia has over 20 commercial airlines; Malaysia is home to Air Asia, the region's largest and fast growing low cost carrier. Thailand has also several leisure carriers such as Phuket Air and Bangkok Airways as well as a raft of new low cost carriers: Nok Air, Thai Air Asia and One-Two-Go. China government sweeping reforms has opened the domestic civil aviation market to the private sector. India is also experiencing extraordinary growth, which is setting to accelerate the air traffic in the country. Air Deccan, Spice Jet, Paramount Airlines are the low cost carriers operating in the country. Around half a dozen new low-cost air carriers are planning to launch and may fly in the Indian air space.

Governments in Asia Pacific region are on the job of capacity management to meet the growing demand. Many countries in the region are seeking private sector model to invest in the airport infrastructure in order to expand the airside and landside management through joint venture. For example, Second Bangkok International Airport Limited (BIAL) and very recently, India has called bidding for Mumbai and Delhi airport. This drastic measure would help the growing travellers with seamless travel without any delay and congestion in the years to come.

Measures for alleviating Congestion and Delays

There is a broad range of measures to prevent and control congestion of airports. These may be classified into short term and long term planning. The short term planning occupies minimal building of new facilities and long-term measures seek to increase physical capacity to meet the current and future demand. Implementation of any one of these measures is often fraught with problems. For example, the main complexity focused in many cities is that the extensive land requirements of airport development and their environmental impacts pretense severe constraints on the provision of extra runway capacity and terminal capacity (ICAO, 1992).

Short Term Planning

Short term planning and management of airport facilities generally revolve around three main strategies:

Applying better management tools and new technologies to improve the traffic flows in the different facility systems
Efforts directed at eliminating restrictions on capacity use
Re-distribution of demand management during the peak hour periods

Formulating to modify the facilities and equipments and devising new methods for a more efficient use of existing facilities constitute the most common step towards improving the airport flow management. All such measures serve to increase the turnaround time of aircraft. Steps should be taken to increase productivity of existing resources like, modifying the layouts, introducing better gate management and improved ATC techniques. Further, the airport authorities should take care of better terminal systems in order to examine carefully the possibilities of implementing flexible allocation strategies for various passenger facilities like, Check-in-counters, immigration counters and customs checkpoints in line with changes in traffic composition. In the runway system, overall efficiency may be increased by properly locating exits, departure queues and bypasses. Consequently, runway occupancy time may be reduced and will have greater flexibility in managing departure queues (FAA, 1996).

Long Term Planning

The long-term plan reveals the development of new physical capacities i.e., building new terminal and runways if the traffic is growing significantly and exploding the terminal as well as runway. There are a number of important issues, which need to be considered in the implementation of long-term expansion of capacity.

Conclusion

Many developed countries are experiencing considerable difficulties expanding their airport capacities in their key cities. North America and Europe, the airports facing congestion due to capital sunk into this mega-infrastructural system, the shift to an option of building a new airport would be costly. The paper has described the concept and theoretical aspects of 'airport capacity' on airside and landside and further it explodes the case study of major airports of US, Europe and Asia Pacific. It is also briefly describes the short term and long term planning of airport capacity. Further, the study also briefly reveals the measures to alleviate airport congestion and delays through short term plan and long term plan and congestion charging mechanism for peaks and off-peaks with the help of Marginal and Average cost pricing structure. Congestion pricing mechanism at airports could be used as the economic instrument of demand management under following conditions " Congestion is a consequence of the relationship between demand and airport capacity causes delays longer than the threshold of 15 minutes, i.e., when the demand / capacity ratio moves or exceeds one".

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Annexure – 1
World-wide Airside and Terminal Declared Capacity Per Hour – 2002

AIRPORT	RUNWAY	TERMINAL	STATE	REGION
Hartsfield	184-200	22000	Atlanta	N.America
O'Hare	150-175	-	Chicago	N.America
Fort Willams	270	22000	Dallas	N.America
Denver	200	15500	Denver	N.America
Halifax	56	3300		N.America
Honolulu	120	12500		N.America
Mc Carran	110	-	Los Vegas	N.America
Los Angeles	153	-	California	N.America
Miami	120	18400	Miami	N.America
St. Paul	125	8000	Minneapolis	N.America
Mirabel	40	-	Montreal	N.America
Newark	108	17000	New York	N.America
JFK	100	31000	New York	N.America
La Guardia	81-100	12000	New York	N.America
Orlando	110	-	Orlando	N.America
San Francisco	120	6000	San Francisco	N.America
Vancouver	80	4600	Canada	N.America
Copenhagen	83-100	4500		Europe
Frankfurt	80-100	14000	Germany	Europe
Brussels	74	-	Germany	Europe
Geneva	38-40	-		Europe
Gatwick	50-60	12000	London	Europe
Heathrow	80-100	20000	London	Europe
Manchester	59	13000	London	Europe
Russia Domo	51	6000	Russia	Europe
Bangkok	60	10500	Thailand	Asia Pacific
Peking	60	9200	Beijing, China	Asia Pacific
Hong Kong	50		China	Asia Pacific
Soekamo Hatta	74	2100	Jakarta	Asia Pacific
Karachi	30	600	Pakistan	Asia Pacific
Lahore	30	1200	Pakistan	Asia Pacific
Kula Lumpur	50	7100	Malaysia	Asia Pacific
Macau	24	4000	China	Asia Pacific
Mumbai	24	5000	India	Asia Pacific
Delhi	24	3500	India	Asia Pacific
Kansai	30	-	Japan	Asia Pacific
Gimpo Seoul	32	-	S.Korea	Asia Pacific
Changi	66	19000	Singapore	Asia Pacific
Kingsford	80	7200	Sydney	Asia Pacific
Taipei	50	12000	Taiwan	Asia Pacific
Narita	44	16000	New Tokyo	Asia Pacific

Source – ACI/IATA/ATAG (ACI, 2003 Edition)
Terminal Capacity – Assessment based on Number of Terminal (Total)
Airside Capacity – Assessment based on IFR/VFR/ATC/Runway/Noise/Terminal