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Getting Planes off the Ground: Key Concepts and Issues in Airport Capacity Planning and Management

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Introduction

An airport is a terminal facility that functions as an interface between air and surface vehicles. It is a processing centre providing the necessary facilities for ticketing, documentation, and control of passengers and cargo (Ashford, et al., 1984). In the early days of commercial aviation development, airplanes were small and the volume of traffic was limited. During that time, the airport system was simply a site with basic facilities such as a short runway, control rooms and a terminal building for passengers and cargo. In recent decades, with the tremendous developments in aircraft technology and the huge growth in demand for air travel, the airport has evolved into a much larger and significantly more complex system. Civil aviation today involves aircraft which can carry more than 400 passengers. This means more passenger traffic has to be processed at a particular time. The largest aircraft, the jumbo jets, can weigh up to 400 tonnes and land at speeds close to 300 kph, and the runways therefore need to be of very hard surface and be much longer. There are also many more airlines and aircraft in service, and this calls for much more sophisticated systems of air traffic control and ground handling.

It is apparent that the high growth in air traffic movements globally will continue unabated into the 21st century. This has drawn attention to the increasing threat of congestion both on the airspace and on the ground (airport) facilities worldwide. Congestion is inherently a spatial problem which arises when the demand for space by aircraft in the air and on the ground, and passenger and cargo movements at the airports exceed the supply (i.e. the capacity). When there is congestion, delays are experienced in that flights cannot take off or land on schedule. Congestion is rarely seen all the time; it is common only during the so-called "peak hours" of aircraft movement at an airport.

The problems associated with congestion include increased operating costs for airlines and a decline in air travel service quality. For example, it is estimated that a Boeing B-747 jet will consume 1,670 kg of fuel if it is held in the air for an additional ten minutes because of inadequate air traffic control systems or runway capacity (Singh, 1994). In the United States, approximately 245,000 flights were delayed 15 or more minutes in 1997. It has been estimated by the Air Transport Association that the total aviation delay costs to air carriers exceeded US$ 2.4 billion in that year (FAA, 1998: 32). Airlines that carry a large volume of connecting traffic find that delays in one airport may affect flight schedules of those connecting flights. Another effect of congestion is that airports simply cannot accommodate more aircraft even though there may be a significant growth in demand for air travel. For example, in Tokyo's Narita Airport airlines intending to increase their flight frequencies have often been turned down on the basis of such airport capacity constraints. The Japan Travel Bureau estimated that for the year 1989, 1.5 million people were forced to forgo opportunities to travel abroad because of this factor (Lam, 1992: 3). Because of the long lead time for construction and the penalties of delays caused by inadequate facilities, it is important to keep a close watch on the trend in traffic movements so that additional capacity can be provided before demand builds up to an untolerable level. This seemingly simple problem is complicated by the fact that airport capacity is best added in discrete large increments (Lim, 1986).

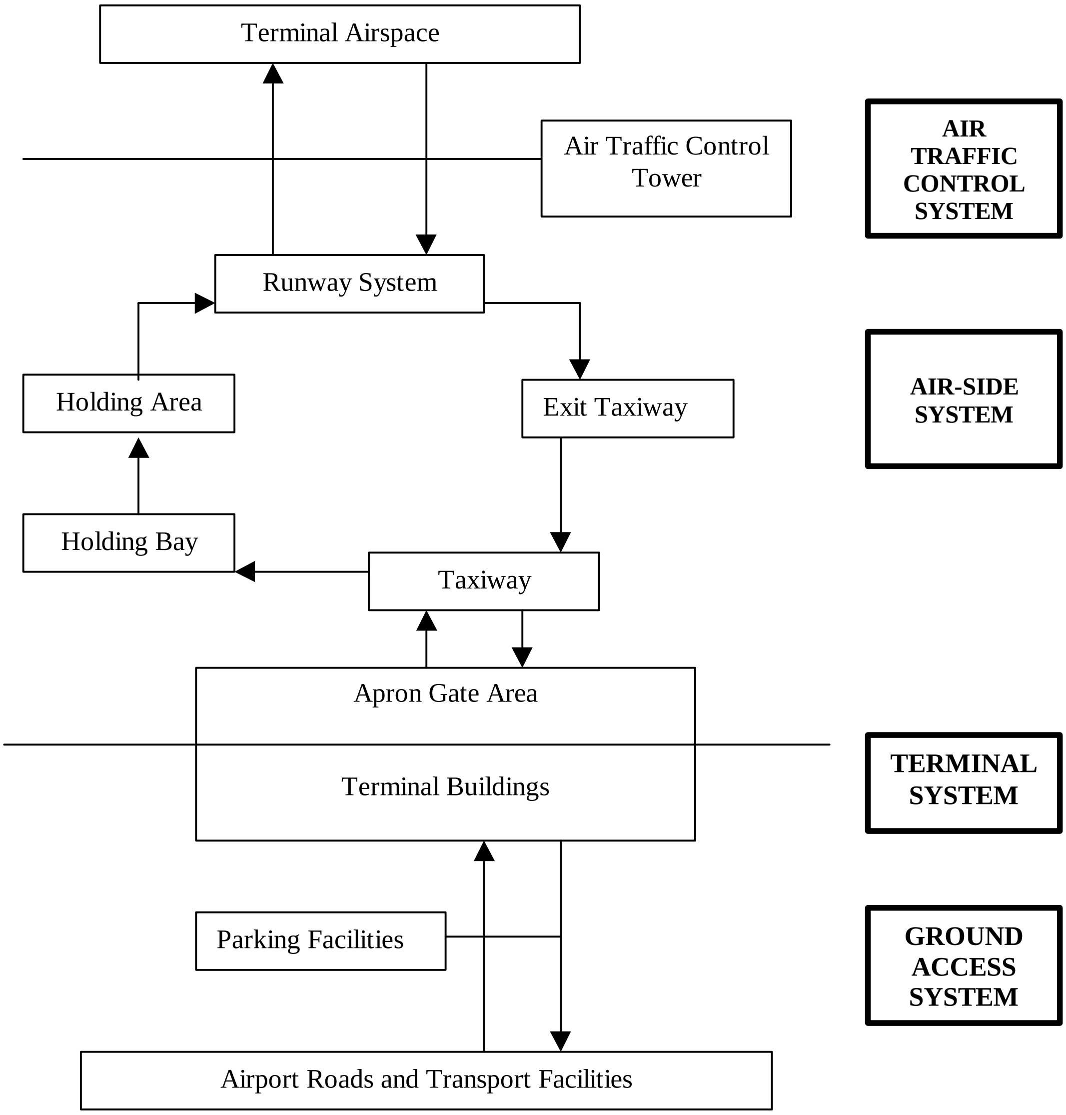
Capacity planning and management at airports should be done without compromising on the convenience and safety of the traveller who desires a fast and smooth transition from the point of disembarkation of the aircraft to the point of exit from the airport (and vice versa). Air and land vehicles have dissimilar operating characteristics and varying spatial requirements and the modal transition processes are challenges the airport administration must meet (Wiley, 1986: 19). The development and use of airport infrastructure also needs to take into account broader societal factors such as environmental effects, particularly noise pollution. This points to the need for a very careful analysis of the trade-offs among desirable but conflicting roles expected of the airport in the overall transportation network of the country. Moreover, modern airports constitute substantial infrastructure investments with log gestation periods, significant opportunity costs of capital, and oftentimes unpredictable patterns of demand (Ashford, et al., 1984; Lim, 1986). The service lives of many airport facilities have also been shortened by obsolescence, brought about largely by the rapid developments in aircraft technology, causing rapid increases in capital and operating expenses (Wiley, 1986: 21).

The focus of this paper is on the planning and management of capacity on the ground to ensure the efficient use of space for traffic and aircraft movement at airports so as to avoid a situation of congestion. Delays would become a norm unless aviation authorities make immediate plans for both short and long term measures to address this growing concern in their respective cities and countries. Airports are made up of many operational areas which are interlocked with one another, and the effective planning and management of capacity can begin only with an understanding of this interacting system. The paper begins with a discussion of the theoretical concerns in airport capacity using a systems framework. This is followed by a broad analysis of the sources of delay and congestion in airports and their abatement measures. Most of what has been written on this topic has tended to focus on a specific sub-system of the airport, especially the runway system. In this paper, I attempt to provide a more comprehensive and integrated treatment of this important issue, drawing insights from actual experiences of airports around the world.

Airport Capacity: Theoretical Issues

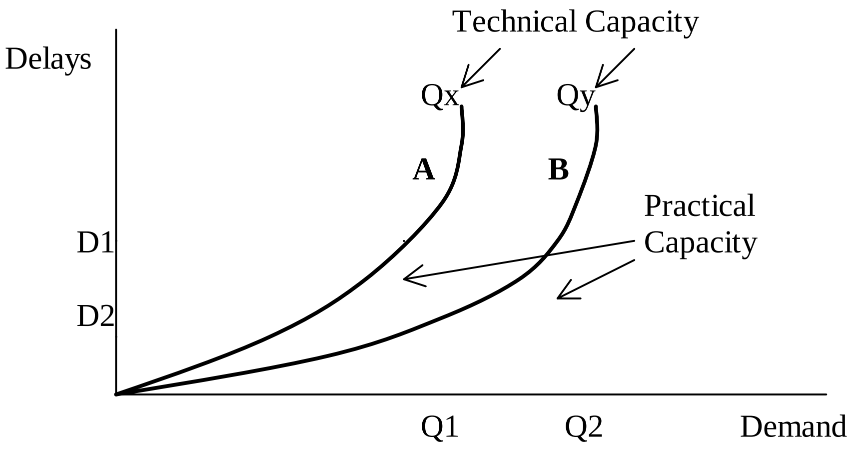
An airport is a complex open system dependent on the interaction of many component parts. From the point of view of congestion and delays, these components may be conventionally divided into four systems which may best be understood by visualising the movement of traffic as the aircraft arrives at an airport. Prior to landing, the aircraft is guided by instructions provided by the *air traffic control system* at the airport. The aircraft lands on the runway, makes its way through taxiways and eventually parks itself in the apron area. The apron area would consist of the parking bays for aircraft as well as the connections to terminal complexes and buildings housing ancillary services such as the catering centres and aircraft service hangars. These facilities are grouped into the *air-side system*. The movement of the aircraft stops and the movement of traffic (passengers, their baggage and cargo) begins. If the aircraft is parked in a remote bay, passengers disembark the aircraft and are taken to the passenger terminal building. On

Figure 1: Components of the Airport System



Source: Adapted from Wells, 1992

Figure 2: Capacity, Demand and Delay Relationships



Source: BCTE, 1995: 86

the other hand, the aircraft may park right next to the terminal building, providing direct access to passengers through the aerobridges. Their checked-in baggage is also sent to this building. The cargo (airfreight, unaccompanied baggage and mail) is taken off the aircraft and sent to the cargo terminal building. The processing of passengers, baggage and cargo takes place in this *terminal system* involving such procedures as check-in, security and customs checks and immigration. Also included is the range of facilities which deal with traffic connecting to other domestic or international flights. In most airports, the domestic and international terminal facilities are separated, requiring some form of access system between them. The *ground transport system* is the final stage in this pipeline, involving all facilities dealing with access into and out of the airport such as land transport curb-side and parking spaces (Figure 1).

The challenge of airport administration is to ensure the smooth and efficient flow through this pipeline of inter-connected systems. If bottlenecks appear in any one system, either through ineffective management, inadequate facilities, or extraneous circumstances, congestion may arise affecting the whole airport system. For example, if the runway capacity is inadequate to meet demands, the problem is inevitably thrown back upon the air traffic control (ATC) system. More aircraft are held in stacks waiting for their turns to land. The ATC authorities may try to alleviate their own problems by introducing 'flow management', which means rotating operations in the air-space and keeping aircraft on the ground until there is a slot for them in the sky (Wheatcroft, 1989). Each facility, whether runway, terminal or ATC, has its own capacity constraints. The overall airport capacity is determined by the weakest link in any one of these facilities. In other words, one has to estimate the capacity of each functional element of the airport system, and the facility with the lowest capacity determines the airport capacity. Ideally, all airport facilities should be synchronised so that they reach capacity constraints at more or less the same time (Urbatzka & Wilken, 1997; Lim, 1986).

Given specified conditions such as safety requirements and standards of convenience and comfort, the capacity of a particular airport facility is the maximum number of traffic units (aircraft, passengers, cargo shipments, bags, etc.) that can flow through the facility in a particular time period, which is usually the hour. In determining the total capacity, two concepts are often used - technical capacity and practical capacity. First, there is the notion of technical or saturation capacity which denotes the total number of aircraft that an airport can handle without regard to any delay, subject to ATC regulations on minimum aircraft separation. Second, there is the practical capacity which is the number of take-offs and landings that can be accommodated with no more than a given amount of delay, usually expressed in terms of maximum average delay (Wells, 1992). Figure 2 illustrates the relationships between capacity, demand and delay with respect to the runway system. The technical capacity for a runway system A is given by *Qx*. In the runway system, a common standard used for acceptable delay for aircraft in the take-off queue is four minutes. Interestingly, in an attempt to expand capacity, "Heathrow Airport has, with the agreement of airlines resorted to declaring capacity equivalent to average delays of 10 minutes rather than the previous standard of four minutes" (Caves, 1997: 129). If the acceptable delay is given by *D1*, the volume of demand which may be accommodated by the runway system A is *Q1*. If the runway system is improved (system B), the curve shifts outwards and the technical capacity increases to *Qy* and the practical capacity to *Q2*. The level of demand that could be practically handled by the previous system can now be accommodated with lower delay (*D2*). The capacity is not a constant value but is rather a function of factors such as the size distribution of aircraft and the ratio of landings to takeoffs.

In the case of terminal facilities, the estimation of capacity is more complex since it has to take into account the type of design, type of traffic (true origin/destination versus transit traffic, for example), type of flights (charter versus scheduled) and layout of facilities within the terminal. Countries adopt different selection criteria for determining the adequacy of their terminal systems. In Germany, for example, the 30th highest hourly volume of the year has been used as a measure for dimensioning infrastructure and facilities at airports. The rationale is that if facilities are planned to accommodate the absolute peak demands of the year, they will be oversized for most of the traffic loadings during the year (Urbatzka & Wilken, 1997: 108).

It should be noted that there has been, in the past, a tendency by airport administrations to focus on runway capacity given the difficulties in adjusting this facility system in response to changes in demand. If an airport is to be viewed simply as a functional entity whose main objective is to make traffic flow smoothly and efficiently through the various systems, perhaps this focus on runway systems is warranted given its low level of flexibility in expansion relative to other systems. Also, much of the literature on the subject of airport capacity has been written with reference to European and North American situation where runway capacity shortages are experienced at airports with the largest traffic flows including airports in London, Frankfurt, Amsterdam, New York, Chicago, and Los Angeles (Caves, 1997: 128).

However, it is apparent that many major airports in other parts of the world face capacity constraints not in the runway system but in the apron and terminal systems. Examples include the international airports at Mumbai and Sydney (ATAG, 1997; 37). Airport authorities are also increasingly having to deal with the 'experiential' aspects of passenger movements through the airport. The consumer revolution has hit the airports and their demands on 'airport service' have grown globally. First, the spaciousness of an airport has become an increasingly important dimension of service quality. Second, the growth of hubbing activity has meant that transfers have to be made at intermediate points between origin and final destination. Passengers are concerned with walking distances between flights and airport authorities have to take this into account in the overall design of the terminal, the specific layout of individual facilities, and with the positioning of aircraft such that connecting flights are located physically close together. Third, there are differences in requirements between business and leisure travellers with the latter considering the airport as the 'start' of their holiday and are usually more willing spend more time and money on concessionnaire facilities (Foster *et al.*, 1995: 174). The burgeoning of the leisure tourist markets globally, and the interest in airport authorities in capitalising of this potential growth of revenue from concessionnaires translates into bigger space requirements of particular facilities. The overall effect of these three factors has been the revision upwards of estimates of terminal space requirements at major airports and the increased attention paid to terminal planning and management.

An example of the difficulty in reconciling capacity maximisation and passenger convenience objectives is seen in the design concept for the terminal. A centralised terminal design offers economies of scale on the use of fixed equipment such as baggage systems and check-in desks and with movable apron equipment. However, it reduces passenger convenience in terms of walking distances. Decentralisation reduces walking distances and facilitates planning of parking facilities. However, it has poor economies of scale. More importantly, decentralisation leads to a loss of daily capacity which results when a given terminal area is broken down into a number of sub-areas. Capacity is determined by peak hour operation and demand peaks are more easily smoothed for one large terminal than two or more small terminals (Ashford, *et al.*, 1984: 10).

The cargo and ground access systems too have been accorded relatively little attention in the literature. These functions have often been regarded as 'poor second cousins' that did not require special planning and management (Rutner & Mundy, 1996). Notions of passenger facilitation and clearance usually involve the time taken between arrival and leaving the airport restricted area after customs checks. If transport facilities are not adequate or are poorly managed, passengers may experience considerable delay in getting to their intended destinations in the city. Long queues of people waiting for taxis are a common sight at many airports and mass public transport services (e.g. buses) are often inadequate or inaccessible. Heavy reliance on private automobiles for airport access has contributed to an increase in demand for parking facilities at major airports. Given the limited space around terminal areas, many airports have moved towards providing remote parking areas in peripheral areas. Parking facilities close to terminal buildings offer lower access time and are usually charged higher fees than remote parking, and these differing characteristics affect the traveller's choice between them. The distribution of parking facilities between these two categories has to be properly planned as "inappropriate parking operating strategies may result in imbalance of parking demand distribution that degrades the level of service and makes parking spaces" idle (Hsu & Lin, 1997: 220; Mandle, *et al.*, 1982).

Unlike passengers who make their own way through the terminal, cargo has to be moved from the aircraft right through to the ground access system where agents collect their shipments for customs checks and clearance. The cargo side of the air transport business has long been accorded a secondary status to passengers. For short-haul flights especially, airport efficiency is an important consideration in the overall competitiveness of air transport relative to surface modes. The time saved on the air is sometimes lost on the ground at many airports because of poor cargo terminal capacity planning and management. The airport authorities and ground handling agents need to coordinate efforts to improve information exchange between the air cargo community, increase efficiency of cargo handling, and streamline documentation procedures to facilitate speedy cargo movements out of the airport.

The capacity of any facility therefore will ultimately depend on the design, state of technology, the human resources inputs, and the range of potential quality and productivity improvements. Often, it may be possible to stretch the capacity, or ease the bottlenecks developing in any facility by management procedures and innovative measures (Lim, 1986). However, there are physical limits that can only be overcome through expanding existing or building new spaces for the facilities. The most problematic is the runway system because capacity usually cannot be increased through 'expansion of existing facilities'. The only way is to add a new runway, a solution which requires very substantial land space. In many countries, such as Japan and Germany, the runway can be regarded as a controlling element of overall airport capacity (Urbatzka & Wilken, 1997).

Sources of Delay

Congestion and delay may be attributed to the variability of capacity (supply) or to the variability of demand at the airport. Although airports have their estimates of their hourly capacity, the actual volume of traffic units which can be handled varies from time to time depending on a number of factors. In other words, given a particular level of physical and management infrastructure, the actual capacity available at an airport may not be constant over time. Demand is not constant but may be bunched during particular days of the week and during particular hours during the day. In most airports, the variability is supply is a relatively more pervasive factor in delays than the variability in demand. Table 1 shows the trends in the distribution of flights delayed 15 or more minutes by primary cause in the United States.

Table 1: Distribution of Flights Delayed 15 or More Minutes by Cause

CAUSE	*1993*	*1994*	*1995*	*1996*	*1997*
Weather	72 %	75%	72%	75%	68%
	197.9	184.6	171.5	201.0	167.0
Terminal Volume	22 %	19 %	18 %	18 %	22 %
	59.4	47.5	43.6	49.8	54.3
Center Volume	0 %	0 %	0 %	0 %	0 %
	0.2	0.2	0.1	0.3	0.1
Closed Runways/Taxiways	3 %	2 %	3 %	3 %	3 %
	8.0	5.7	6.7	7.9	8.1
NAS Equipment	2 %	2 %	3 %	2 %	3 %
	4.7	4.0	6.3	5.9	6.4
Others	2 %	2 %	4 %	2 %	4 %
	5.5	5.8	8.5	6.6	9.6
Total Operations Delayed (000s)	276	248	237	272	245

Source: FAA, 1998: 25.

Supply factors

One of the key assumptions behind the estimation of technical and practical capacities is that airport functions can be carried out smoothly without malfunctioning of equipment or airport workers going on strike. From time to time, many major airports have witnessed breakdowns in equipment and facilities such as navigation aids (for example, radar and lighting) and traffic processing systems with the consequence of congestion and delays throughout the airport system. A good example relates to the fire incident at Subang International Airport in Kuala Lumpur in 1993 which knocked out the terminal approach radar, forcing air traffic controllers to manually guide aircraft to land and take off. It has been noted that airlines using the airport had to incur in excess of US$70,000 daily for additional fuel and other operating costs following the Malaysian Department of Civil Aviation's decision to stack up aircraft in the airspace (Singh, 1994). More recently, the teething problems with various airport computer systems in the Chek Lap Kok Airport in Hong Kong and the new Kuala Lumpur International Airport have received considerable attention.

It is the responsibility of the airport administration to ensure that human resources are effectively managed and that equipment and other physical facilities are well-maintained. With increasing automation of airport functions, it is imperative that flexibility is built into the way the systems may be operated. There also needs to be in place a good crisis response and management system to provide plans for alternative courses of action in the event of a breakdown in vital activity areas so that the airport is able to continue functioning without bringing about significant delays.

Construction activity to carry out expansion or renovation of facilities at the airport may also represent another source of variability. This is an important factor which is not adequately highlighted in the literature. A certain portion of a particular facility may have to be closed to allow for upgrading or renovation works and, consequently, processing of traffic has to be accommodated within the remaining portions of that facility. This is why upgrading work on airport facilities is usually undertaken in phases. It is therefore important that such expansion and renovation work be carried out well before the facility reaches saturation point so that traffic processing may still be executed smoothly under a temporarily reduced capacity situation. The amount of reduction would be small if expansion is through facility addition but it may become significant if it involves facility conversion. The experience of many airports shows that expansion is only considered seriously when the capacity situation is critical, but such expansion becomes difficult because it effectively reduces some of the already tight capacity.

Restrictions in the operating hours of an airport can also present problems in capacity management. An airport which is operational for 24 hours has the flexibility in dealing with slot allocation for flights in that flights can be spread out over a long period. Delays in landings and take-offs resulting from airline scheduling problems may be accommodated more easily without affecting the overall airport system. The same flexibility will not be presented for example to an airport which has to be closed during the night because of noise curfews. In many cities, there are also limitations on the maximum number and types of aircraft allowed to land or take-off during particular times. The situation of an airport in relation to nearby airports and in relation to obstacles both natural and of the built environment may further impose restrictions on the specific paths which aircraft may take to and from the airport (Wells, 1992).

In the airspace, congestion occurs when more than one aircraft plan to fly at the same level along a preferred route at about the same time. The amount of delay depends on the number of aircraft ahead, the safe separation minimum between successive aircraft and whether there are diversionary routes (Wong, 1992). ATC rules and procedures have an especially important influence on capacity and delay at airports where two or more runways may be in use at the same time or where there might be several arrival streams that must be merged on one final approach path (Wells, 1992: 195). In many countries, ATC systems are ageing and large investments are required to bring new technology into the air transport system (ICAO, 1992: 12). For example, ATC problems in Bangkok hold the runway capacity to a much lower level than the declared capacity (ATAG, 1997: 37).

A significant factor behind supply variability is weather conditions. In the United States, about 68 per cent of delays of 15 or more minutes were due to poor weather in 1997 (see Table 1). Conditions affecting visibility and prevailing wind (fog, rain, snow, etc.) may affect the spacing between aircraft take-offs or landings. The airport capacity is highest during calm, clear weather. As a general rule, the runways at an airport have to be oriented as closely as possible to the direction of the prevailing wind in order to keep the wind component at right angles to the runway (cross-wind component) to a minimum. At some airports, because of the frequent changes in the direction of winds, an intersecting system of runways is required (Goh, 1982). Therefore, even though more than one runway is available, only one may be functional during particular periods.

Demand factors

If airport capacity is derived for traffic units over the period of one week and this is compared with the levels of airport demand over the same time period, it may well be the case that most airports would not have a problem in terms of inadequacy of facilities. Unfortunately, demand is almost never spread out evenly over a week. The distribution of arrivals and departures of aircraft is not uniform during different hours of a day and during different days of a week. This is perhaps the single most important factor behind airport congestion and delays in most airports. Demand is usually highest during the weekends, and during a typical day, it would be highest usually in the early morning and evening periods. It is in the interest of airports to serve as much traffic as possible and many of them would strive to provide capacity in line with peak hour demand. However, this often means that during non-peak hours, capacity may be significantly underutilised.

Also to be considered is the composition of demand with respect to the type of aircraft used by airlines. The amount of in-trial separation required between aircraft is a function of its size. It is lowest between two small aircraft, for example the types of aircraft commonly used by commuter airlines. However, "when smaller aircraft follow heavy jets, much greater spacing is required to avoid hazards of wake turbulence. In addition, controllers must use increased spacing to ensure that the slower small aircraft is not overtaken by the faster jet aircraft. Generally, runways are most efficient when their use is limited to aircraft of similar size and approach speeds" (FAA, 1996: 7).

Increased passenger loads from jumbo jets necessitates extra space in terminal check-in, waiting rooms, baggage make-up and corridor areas. This is necessary not only to handle larger numbers of passengers but also to provide for surges that occur when 400 passengers at a time enter the inbound and outbound processing centres (Wiley, 1986: 24). For large international airports, because of the mix of destinations served, those travelling short-distance trips arrive as little as half hour before departure whereas those on long distance trips arrive perhaps one and a half to two hours before departure. These differences must be reflected in the type of facility provided. Successful airport relies on forecasting the volume and mix of demand and building, as flexibly as possible, to meet it (Marshall, 1988).

Aircraft departure and arrival times for international airports are decided during slot allocation committee meetings held well in advance of the proposed flights. However, the fact of the situation is that airlines often do not keep to their schedules in arrival and departure times for reasons outside of inadequacy in airport facilities. The most common reasons for this happening are technical problems faced in the aircraft and traffic facilitation. The latter includes checked-in passengers not showing up at the boarding gates on time and aircraft waiting for connecting traffic from other delayed flights. For airports which play an important hubbing role, it may be the case that an aircraft waiting to take-off may be getting a significant share of its passengers from another incoming flight which has been scheduled to arrive just 30 minutes earlier. At a particular international airport, it is expected that most of such hubbing activity is carried out by the national carriers (sixth-freedom international traffic as well as international-domestic traffic transfers). The reliability of the national carrier in terms of on-time performance significantly affects the overall performance of an airport. With the increased adoption of the hub-and-spoke concept by airlines both in domestic and international sectors, this source of delays is becoming more serious but it has been practically overlooked in previous studies on airport capacity.

Measures for Alleviating Congestion and Delays

Up till the mid-1980s, the experience of many airports all over the world suggests that serious large-scale efforts to improve capacity provision and management are undertaken only after the delay situation becomes critical. However, it should be noted that there has been a change in attitude in recent years on the part of aviation authorities and governments. They are increasingly taking a more forward-looking approach, giving more attention to the assessment of traffic growth potentials, and drawing up long-term plans to accommodate traffic increases as they come. This approach is witnessed especially in the international airports in Asia-Pacific countries, which are aggressively competing with one another to attain the position of dominant hubs in the region.

There is a broad range of measures to prevent and control congestion at airports. These may be classified into short-term measures that involve minimal building of new facilities and long-term measures which seek to increase physical capacity to meet current and future traffic volumes. Implementation of some of these measures is often fraught with problems. For example, the main difficulty faced in many cities is that the extensive land requirements of airport development and their environmental impacts pose severe constraints on the provision of extra runway capacity and, to a lesser extent, terminal capacity (ICAO, 1992: 12). Airport authorities, in their attempts to achieve technical objectives (such as maximising efficiency in the use of runway and terminal space), have to take into consideration the welfare of the airport users and nearby communities. This therefore takes us back to the consideration of the need to plan and manage airports from a total systems perspective.

Short-term planning

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

- application of better management tools and new technologies to improve flows of traffic in the different facility systems
- efforts directed at eliminating restrictions on capacity use
- management and redistribution of demand particularly during the peak periods

Making modifications to facilities and equipment and devising new methods to allow for a more efficient use of existing facilities constitute the most common first step towards improving the management of airport flows. All such measures serve ultimately to increase the turnaround time of aircraft. Steps may be taken to increase productivity of existing resources such as modifying the layouts, introducing better gate management, and implementing improved techniques for air traffic control. For example, within the airport terminal systems, airport authorities may want to examine carefully the possibilities of implementing flexible allocation strategies for such facilities as passenger check-in counters, immigration counters and customs checkpoints in line with changes in traffic composition. It is important for airport authorities to involve the different system users frequently in operational decision making (FAA, 1998: 26).

In the runway system, overall efficiency may be increased by properly locating exits, departure queues, and bypasses. Consequently, runway occupancy times may be reduced and controllers will have greater flexibility in managing departure queues (FAA, 1996: 7). For example, the building of 'acute-angle' taxiways in place of 90-degree taxiways allows aircraft to exit the runways faster. In the ground access system, to avoid mixing fast moving cars and buses going to the passenger terminal from slow moving cargo trucks going to the airfreight terminal, separate road access could be provided. Measures for the air traffic control system include technical procedures such as revisions to criteria on the separation between aircraft; more visual approaches to allow for flights to intercept the final approach path nearer to the runway threshold, thus reducing holding time in the air; and implementing parallel runway operations (Wong, 1992). Table 2 illustrates the impact of technology improvements in the runway system at Kingsford Smith Airport in Sydney. The implementation of independent parallel runway operations using PARM (Parallel Approach Radar Monitor) systems has been especially successful in increasing runway capacity. Improved methods of airspace resectorisation as a result of recent redesign studies undertaken particularly in the United States are also yielding efficiency benefits.

In order to ensure that the overall airport system is operational to handle capacity volumes, regular maintenance of individual facilities is necessary, especially for key facilities such as runway pavements, radar equipment, and baggage handling systems. Round-the-clock computer monitoring of operational systems for failure detection is useful and this needs to be complemented with the ready availability of maintenance staff support, and spare parts and equipment. Even if considerable effort has been put into ensuring that all systems are running smoothly at all times through regular checks and maintenance, there is still a possibility of equipment failures due to various unforeseen circumstances. Comprehensive back-up plans need to be in place so that delays are kept to a minimum in the event of such failures.

Table 2: Runway Movement Rates at Kingsford Smith Airport in Sydney

Runway(s) in Use	Movements per Hour
Single Runway - IFR	30 - 36
Single Runway - VFR	36 - 40
Two Runways - IFR	40 - 44
Two Runways - no SIMOPS	44 - 48
Two Runways - VFR, SIMOPS	48 - 65
Phase 1 Parallel Runways - existing tower	50 - 55
Phase 1 Parallel Runways - new tower, VFR	60 - 65
Phase 1 Parallel Runways - new tower, PARM	80+

IFR: Instrument flight rules
VFR: Visual flight Rules
SIMOPS: Simultaneous runway operations
PARM: Parallel Approach Runway Monitor

Source: BCTE, 1995: 15

One clear means of enhancing capacity is to replace obsolete equipment with new technologies. Significant progress has been achieved in developing capacity-enhancing technologies in practically all aspects of airport operations. For example, in the area of air traffic control, a new Long Range Radar and Display System (LORADS II) is now available which can make highly accurate computations of aircraft movements 20 times faster than the previous LORADS I system. In passenger terminal operations, a new system called CUTE (Common Use Terminal Equipment) operating system has been developed which helps to ease congestion at all stages of the check-in and pre-flight boarding process, playing an important role in keeping flight departures to schedule. Before the CUTE-OS system, passenger details at the departure gate were manually keyed into the system. Now a ticket reader does that automatically. The effect is smoother flow of passenger traffic at departure gates and increased accuracy. This is a vital function as flights cannot depart without a complete and accurate passenger manifest (*Business Times*, 23 November 1994).

Technological development is particularly visible in the area of automation (Khan & Roovers, 1995). To an increasing degree, airport design and renovation must include the facilities to support large scale automation. Airlines and ground handling agents must work more close with airport authorities to ensure that automation needs of all airport users can be met without expensive modifications later on (Wineberg, 1987: 141). According to the US Federal Aviation Administration, significant capacity enhancements in air traffic control can be potentially gained in the next two decades with increased capabilities in the areas of communication, navigation, surveillance, weather, and decision support systems in air traffic management (FAA, 1998: 4). In terminal operations, the progressive introduction of machine-readable passports and the general streamlining of facilitation procedures will be of increasing importance in the continuing search for improvements. In some airports, the use of electronic data interchange systems to facilitate customs clearance of cargo shipments before flight arrival has been effective in improving ground transport operations (cargo trucks) out of the cargo terminal.

In the area of eliminating restrictions on capacity use, a few possibilities exist but they are dependent on the concerted efforts of governments, airport authorities, airlines and neighbouring communities. For example, in airports where there are night restrictions or curfews, a dual joint effort may be taken firstly on the part of airlines switching to quieter aircraft and secondly, airport authorities working with communities to convince them that aircraft are actually getting quieter (Doganis, 1992: 39).

The last set of measures are those directed at the demand side, wherein the focus is to achieve a better distribution of traffic away from the peak-hour periods. Any scheme of demand management denies some users free or complete access to the airport of their choice. Attempts to manage demand are also criticised for adversely affecting the growth of the aviation industry and the level of service to the travelling public. In the case of major international airports, it is in the interest of the airport authorities to accommodate as much as possible the needs of airlines in terms of flight frequencies and specific landing/take-off times. This is especially the case for countries where international trade and inbound tourism have an important place in the national economy and where the air transport system serves as the key facilitator to these activities. Expansion of airport facilities either through incremental short-term capacity and productivity enhancement measures or long-term expansion is always desirable but it may be economically restrictive, in terms of societal and other costs. Also, large scale measures such as construction of new facilities involve long lead times. Under such constraints and circumstances, there may be a need for shorter term demand management measures. Many industry observers have taken the position that some form of airport use restrictions especially during peak hours will become increasingly important in dealing with delay and in utilising existing airport capacity efficiently (Wells, 1992: 199).

A method of demand management commonly used by airport authorities is the imposition of bans on certain aircraft types. It has been noted that runway acceptance is greater when the performance characteristics of aircraft is similar. To maximise usage of long runways, major international airports which face inadequate runway capacity problems usually introduce traffic distribution rules that restrict the smaller aircraft. These smaller aircraft may be channelled to a secondary airport. For example, in Singapore's Changi International Airport, turboprop aircraft and those with less than 40 seat are not allowed. While bans based on aircraft size may lead to better allocative efficiency, those bans which are based on environmental factors such as noise curfews may actually lead to inefficiencies. Cargo airlines often prefer night flights and the difficulties in obtaining night slots may result in reduced ability to meet express shipment deadlines for next-day deliveries (Sub-committee on Aviation, 1996: 13). Night bans in many European and Asian airports also restricts the available time windows for flights between these two regions. For an airport such as Hong Kong, departures to Europe can only be scheduled in the late morning or between 2300 and the airport closure at 2330. Departures before 2300 would produce arrivals in Europe at hours when airports there are still closed by curfew (ATAG, 1997: 32). Taking into account such bans on aircraft types as well as other restrictions such as noise curfews, a quota is normally established by the airport operator on the number of slots available per hour on the basis of practical capacity of the airport.

Slot allocation in most countries is carried out under guidelines established by the International Air Transport Association (IATA). Twice a year, meetings are held in which airlines request slots at the particular international airport from its designated slot coordinators, usually comprising representatives of the national flag carriers or a government body. In allocating slots, coordinators are supposed to balance requests from domestic and international airlines with the airport's capacity (Sub-committee on Aviation, 1994: 14). Allocation is done based on an agreed set of criteria. Airlines have the right to retain those slots that they used in the preceding season (historical or grandfather rights) based on the principle of rewarding airlines for past investments in developing routes. Another consideration is the financial impact on an airline of not obtaining a desired slot. Usually, once airlines are assigned slots, they are able to swap them subject to the coordinator's approval who would try to ensure that the slots exchanged have broadly similar operating characteristics. National carriers, by virtue of the international airport being their home base, usually have many more historical slots and greater flexibility to adjust their operations than other airlines (BCTE, 1996: 23; Sub-committee on Aviation, 1994: 14).

While this method is widely used around the world, the inherent bias of the system in favour of incumbent airlines has been noted as a problem. New entrants at an airport may be straddled with uncompetitive slots and consequently not be able to develop their schedules in line with the market. This method of demand management generally works best in a situation where airport capacity is sufficient to meet the airlines' demand or access. However, when there is excessive demand, as would be expected during peak hours, the system may result in allocative inefficiencies. Under these circumstances, it may be desirable to adopt some kind of pricing mechanism for allocating airport capacity. This approach to managing demand can ensure that first, scarce capacity (slots) is allocated to those airlines who will obtain the greatest benefit and second, provide a guide for future airport investment decisions (BCTE, 1996: 24).

In most airports around the world, airlines are charged landing fees according to the weight of the aircraft used. The charges are invariant with respect to the time of take-off/landing of the aircraft. Using a pricing mechanism for allocating capacity necessitates a deviation from this practice. The theory underlying the economics of congestion suggests that users of a transport system do not take into account the full costs of the decisions on usage of the system. Airlines only consider the unit cost (average cost) of scheduling a flight during a period which includes operating costs and time costs. Airlines do not consider the fact that their decision to use an airport imposes additional cost (marginal cost) on others who want to do the same. To optimise the use of capacity, the price (landing fees) should be set at a higher level which reflects these additional costs associated with congestion. While theoretically elegant, it is difficult to determine the appropriate peak period fee that would suppress demand to the social optimum.

In practice, the method that has been used in some airports, particularly in North America and Europe, to control demand during peak periods is to impose a landing fee surcharge. The rationale is that those airlines who value most the peak hour schedules would be willing to bear the higher charges and the lower value users may be motivated to shift their flights outside of the peak period. Peak hour surcharges have been imposed on general aviation in the three major airports in New York since the late 1960s. On the other hand, airports may want to provide an incentive for airlines to schedule their flights at periods when very low capacity utilisation is experienced. At Singapore's Changi Airport, for example, no peak period surcharges are applied but an off-peak discount on landing fees is given to flights arriving or departing between 0200 and 0600 local time, subject to the condition that the aircraft used meets specified noise emission standards (Boeing, 1999). Another method which may be used for allocating capacity is slot auctions. After fixing the number of slots per hour on the basis of estimates of practical capacity, the individual slots are auctioned to airlines and they are sold at the highest bid price. The reasoning behind slot auctions is that when airport slots become a scarce resource, access should only be granted to the users who are willing to pay the market-determined price (Grether, *et al.*, 1989).

Long Term Planning

Essentially, if the growing air traffic demand is to be accommodated, airport authorities have little choice but to add to the physical capacity through building new facilities. Airport authorities would have to examine carefully the trade-off between the amortised costs of expansion and of congestion and delay to determine the timing and scale of investment. This depends largely on the initial capacity and the trends in growth of demand (Oum & Zhang, 1990). In large cities with more than one congested airport, there is also the question of which airport should be selected first for expansion. One way is to make comparisons on the returns to scale and long run marginal costs. In one such comparison undertaken for Heathrow, Gatwick and Stansted airports in London by Tolofari, *et al.* (1990), it was found that Heathrow and Gatwick had significantly higher returns to scale and lower long run marginal cost than Stansted. They suggested on this basis that Stansted should be strongly encouraged to increase its throughput with minimal further investment (i.e. increase its productivity), while Heathrow and, to a lesser extent, Gatwick should be encouraged to expand their facilities.

Naturally given the high levels of investment placed in developing airport facilities, the most preferred option would be to expand continuously the facilities at existing airports. However, this may be hampered by scarcity of land, urbanisation, and environmental constraints. Capacity expansion is particularly difficult for the runway system because of the large amount of land required and the impacts of noise on nearby communities. A good example is difficulties experienced at Tokyo's Narita Airport where a second runway remains stuck on the drawing board because of lack of community support. The government has offered to relocate some 200 families who would be affected by the noise generated by the second runway, and most locals have sold up and moved, while. But there are still two families occupying six hectares, whose refusal to sell means the second runway looks unlikely to be built by the planned date of 2000. A planned third runway remains a distant future (*Business Times*, 26 May 1998).

The option of building a new airport to complement an existing airport may be available but there may be problems in distributing traffic between them. Most airlines would want to use the airport which passengers prefer and this usually is the one which is closer to the city. The last option is to cease operations of the existing airport (especially if it cannot be expanded) and build a new airport which has substantial provisions for further expansion. Many cities in Asian countries have opted for this option, including Singapore, Kuala Lumpur, Osaka and Hong Kong.

There are a number of important issues which need to be considered in the implementation of long-term expansion of capacity. In the case of expansion of land-side facilities such as terminals and ground access systems at the existing airport, it is likely that capacity levels may be reduced during the period when construction is taking place. As such, it would be ideal if expansion is carried out before congestion is experienced so that the temporary shortfall in capacity will not pose a problem. Once the new facilities have been completed and become functional, there will be a situation of overcapacity at least in the initial years. The airport authority should capitalise on this opportunity to carry out improvements in the old facilities to ensure that service levels are comparable. Marked differences in levels of service between old and new terminals witnessed in the London-Gatwick and Paris- Charles de Gaulle terminals have been a source of criticism by airlines assigned to the older terminals (Sub-committee on Aviation, 1994). It is also imperative that the new facilities be opened for use only after all the systems have been subjected to numerous trial runs. The rushed opening of Chek Lap Kok Airport in Hong Kong and Sepang Airport in Kuala Lumpur in 1998 before full testing of the computer systems proved to be costly mistakes.

Conclusion

While many countries in the developed countries are experiencing considerable difficulties expanding their airport capacity in their key cities, Asian countries including Korea, Macau, Malaysia, Hong Kong, China, Pakistan and Thailand have recently opened or are building new airports. In Asia, there seems to be a realisation that the region will be the beneficiary of the highest rates of growth in air travel and many countries are aspiring to establish their main airports as regional hubs. The competition is especially intense in Southeast Asia characterised by the massive expansion of airport facilities in all the countries. With the Asian economic downturn, these huge investments have been called to question and there are concerns about whether problems of serious overcapacity will emerge. In the final analysis, a situation of overcapacity, unless very appreciable, is a smaller problem than undercapacity. At least in the case of overcapacity, there is an open window for growth possibilities. In North America and Europe, the airports facing congestion are already very large and because of the considerable amount of capital sunk into this mega-infrastructural system, the shift to an option of building a new airport would be costly. With the lack of community support for expansion at current sites, the airport authorities will probably have to examine more closely the need for demand management measures to keep congestion and delays under control. This effectively means airports are turning away traffic and thus giving up significant opportunities for the development of lucrative tourism and trade. The airport authority may be running a profitable operation but the wider national economic benefits that are forgone may be even greater.

The air transport industry is well known for its dynamism. The global wave of deregulation will lead to greater consolidation of hub and spoke networks and this may add more pressure especially to the congested airports in Europe where deregulation has just taken off in a big way. Alongside these developments in the airline industry, airports are also going through a period of change in terms of their management. Privatisation of airports is a growing trend in developed countries and the long term implications of this on airport capacity planning and management have not been sufficiently evaluated. Numerous new developments in technology in air traffic control and terminal systems offer considerable scope for capacity enhancement but these technologies often come with a big price tag. However, there is room in many airports to explore their operations to identify potential areas for improvement without the application of new technologies. Airport authorities need to have regular consultations with the ground handling agents and other agencies as well as with the customers (airlines, passengers and freight agents) may well open up new possibilities for capacity enhancement and service improvement. The authority should play a pivotal role in bringing about a concerted effort in traffic facilitation through and out of the airport and in monitoring the performance of the different agencies. The underlying message which comes out of the numerous examples raised in the paper is that the provision of adequate capacity alone through huge infrastructural developments and various enhancements to individual sub-systems is not enough. The facilities have to be properly managed to realise an effective coordination of all sub-systems. The mark of a good airport is not the facilities it has or the grand designs but its ability to perform its functions efficiently with a high level of service to its customers.

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