RUNWAY CAPACITY STUDIES FOR MAJOR INDIAN AIRPORTS

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Abstract

The two principal measures of performance of Air Traffic management (ATM) systems are Capacity and Delay. Significant growth in Indian air traffic is causing congestions and hence delays in the en-route airspace and at airports. The main reason for the delay at airports is insufficient capacity in terms of facilities such as runways, taxiways or gates to accommodate peak period demands. The delays at airports would cause inconvenience to the passengers, airliners and the airport authorities. The airport runway capacity information will be useful to manage demand and minimize the delay. Prediction of runway capacity aids in developing strategies for efficient air traffic management. This paper presents the airport runway capacity studies carried out using Time Space diagrams for major Indian Airports.

Keywords: Capacity, Delay, Runway capacity, Time-Space analysis, Fast time simulation model

Introduction

In recent times, air traffic has increased drastically in the Indian sub-continent. This increase in air traffic growth has resulted in unacceptable delays for passengers and congestion in both airfield as well as airspace. The efficient movement of aircraft between airports is highly dependent on two key characteristics of an airports operation: the demand for service by aircraft operators and the capacity at the airport. In general, if air traffic demand exceeds airport or airspace capacity, delays will occur. The task of managing airports either by providing sufficient capacity to handle demand or managing the demand itself is a challenging one.

Airport capacity studies will help in understanding the handling of aircraft movements in airside area and the associated delays. Towards the airport capacity studies, it is necessary to understand the airport as a system.

Airport System

The capacity of an airport is a complex issue [1]. Several elements of the airport facility including both airside and landside have to be examined to determine the capacity. The schematic of a typical airport is given in Fig.1.

The airport Airside area consists of terminal airspace, runways, taxiways, and apron/gate complex. The terminal airspace accommodates the arrival aircraft just before landing and the departure aircraft just after taking-off. The runways accommodate the ground phase of landing and taking-off. Taxiways physically link the runway and apron/gate complex and enable the aircraft taxiing between runway and gates. At apron/gate complex, the aircraft perform their ground handling service [2].

The airport capacity typically refers to the capacity to handle aircraft operations. Airport capacity analysis [3] serves two purposes: (1) to estimate the ability of various components of airport system to handle aircraft movements and (2) to estimate the delays experienced in the system. Most of the airport capacity analyses have concentrated on the runway component of the airport system. One of the characteristics that affect an airport’s capacity is the configuration of its runway system.
The Airports Council International (ACI) and International Air Transport Association (IATA) guidelines for airport capacity/demand management (1996) defines the most significant aspect of an airport’s capacity as the Runway System Capacity, which is the hourly rate of aircraft operations which may be reasonably expected to be accommodated by a single or a combination of runways under given local conditions [4].

The single runway is the simplest of runway configurations and can accommodate up to 99 operations per hour for smaller aircraft and approximately 60 operations per hour for larger commercial service aircraft during fair weather conditions, known as visual meteorological conditions (VMC), or operating under visual flight rules (VFR) [5].

Capacity Studies

The concepts of airport airside capacity studies and runway capacity studies are explained in this section. The procedural steps towards the estimation of runway capacity using Time-Space analysis are also explained.

Airport Airside Capacity

In this paper, the capacity studies are confined to airfield i.e. airport airside area. For airport planning, airfield capacity is defined in two ways [6]. The first definition says that the capacity is the number of aircraft operations during a specified interval of time corresponding to a tolerable level of average delay. This is referred to as practical capacity and same as the one illustrated in Fig.2. Here the capacity is defined in terms of delay.

The other definition says that the capacity is the maximum number of aircraft operations the airfield can accommodate during a specified interval of time when there is a continuous demand for service. This is normally referred to as throughput capacity and not defined in terms of delay.

Practical hourly capacity is defined by FAA [6] as the number of operations that may be handled at an airport that results in not more than 4 minutes average delay during the peak period, hourly. The definitions of throughput capacity and practical capacity are illustrated in Fig.2.

A fully developed single-runway airport can operate at an average rate of 48 aircraft movements per hour [2]. If daily operation time would be 17 hours per day during 365 days per year, the total airside capacity would be 297340 aircraft movements per year. Generally, this is termed as long term capacity.

Capacity and delay can be evaluated by the use of analytical and computer simulation models [7]. The analytical models are often referred to as mathematical models and generally represent the systems in a simplified manner. Computer simulation models are extremely useful for studying complex systems which cannot be represented by equations. The prime justification for using the computer simulation is to reduce the difference between the real world and abstract world of the model.

The next section discusses the runway capacity. The procedural steps involved in the estimation of runway capacity using time space diagrams are also presented.

Runway Capacity

It is already mentioned that most of the airport capacity analyses have concentrated on the runway component [3]. Runway capacity can be expressed as capacity related to delay and capacity not related to delay.

Runway Capacity (Related to Delay) Estimation

Runway capacity related to delay uses the models which rely on steady state queueing theory [4]. Essentially there are two models, one for runways serving either arrivals or departures and the other for runways serving mixed operations. For runways, exclusively used for either arrivals or departures, the capacity model is based on simple Poisson type queue with a first come first served principle. The demand process for arrivals or departures is characterized as a Poisson distribution with a special arrival or departure rate. For mixed operations where the runways are used for both arrivals and departures, the arrivals will have the priority over the departures for the use of runways. The departure process is assumed to follow a Poisson distribution, however, the arrival process is assumed to follow airborne queuing system.

Typically, when traffic volumes reach practical hourly capacity levels, average aircraft delays may range from 2 to 10 minutes. Consequently for the same specific conditions, this capacity values (not related to delay) may tend to be slightly higher than those observed in related to delay.
Runway Capacity (not Related to Delay) Estimation

Runway capacity not related to delay is defined as the ultimate or maximum aircraft operations rate for a set of specified conditions, and is independent of the tolerable level of average aircraft delay. The runway capacity not related to delay may be referred to as Ultimate or Saturation Capacity. In this, the capacity is equal to the inverse of a weighted average service time of all aircraft being served. The runway service time is defined as either separation in the air in terms of time or the runway occupancy time, whichever is larger. The time space diagrams [8] are generally used to estimate headway between operations at various transportation facilities. Spacing between operations and capacity of transportation systems. Capacity with Time Space diagram

A time space diagram is a two dimensional graph which may be used to represent the location of any particular object, such as an arriving or departing aircraft, at a given point in time. With a time space diagram, visual representations of aircraft movements, based on performance characteristics and FAA regulations may be made. Time Space analysis is a simple technique to assess runway capacity if the headway between the aircraft is known. Headway (h) defined as the time separation between two successive aircraft (T_i - T_j).

Where T_i is the arrival time (to the runway) of the lead aircraft

and T_j is the arrival time (to the runway) of the following aircraft.

The basic idea is to estimate an expected headway, E(h), and then estimate capacity as the inverse of the expected headway.

\[
Capacity = \frac{1}{E(h)}
\]

Where E (h) is expressed in time units (e.g., seconds).

The important factors that affect runway capacity are the runway configuration, runway occupancy time (ROT), aircraft mix, weather conditions, arrival-arrival, arrival-departure and departure-departure separations and arrival and departure procedures. The ATC applies a minimum separation rule of two minutes between two successive arrivals/landings [9].

The capacity of a runway handling only departures is known as Departure Capacity and the capacity of a runway handling only arrivals is known as Arrival Capacity. The capacity of a runway handling both arrivals and departures is called as the runway’s mixed-use operating capacity. In general, a runway’s mixed use operating capacity is determined first by estimating the arrival capacity and then, taking advantage of the times that runway is idle because of the longitudinal separations requirement, allowing departures to occur. The usage of the times that runway is idle because of the longitudinal separations requirement, is known as the Gap Analysis.

Procedural Steps to Estimate Runway Capacity

The algorithm [1] explained below can only estimate the saturation capacity of a single runway. The algorithm can be extended to more complex airport configurations.

Step 1: Enter runway operation technical parameters.
- Arrival minimum separation matrix (δ_i,j).
- Departure-departure separation matrix (ε_i,j).
- Arrival-departure minimum separation (δ).
- Common approach length (γ).
- Runway occupancy times (ROT_i).
- Runway departure times (t_d).
- Aircraft mix (P_i).
- Standard deviation of intrail delivery error (S_o).
- Probability of separation violations (P_v).

Step 2: Compute Expected value of ROT times (E(ROT)) → E(ROT_i).

Step 3: Estimate the "Error-Free" separation matrix, T_{ij} values using opening and closing cases.

Compute expected value of the error-free matrix E(T_{ij}). Since aircraft approaching a runway arrive in a random pattern we distinguish between two possible scenarios:

- Closing case - Instance when the approach speed of the lead aircraft is less than that of the trailing aircraft (V_i ≤ V_j).
- Opening Case - Instance when the approach speed of lead aircraft is higher than trailing aircraft (V_i > V_j).
Where \( V_i \) and \( V_j \) are speed of leading and trailing aircraft.

Step 4: Estimate the Buffer separation matrix, \( B_{ij} \) values using opening and closing cases Compute expected value of the buffer matrix \( E(B_{ij}) \).

Step 5: Compute augmented separation matrix, \( A_{ij} = T_{ij} + B_{ij} \) (error-free + buffer).

Step 6: Compute the probability matrix (i follows j). \( P_{ij} \).

Step 7: Compute expected value of \( A_{ij} \) matrix, \( E(A_{ij}) = E(T_{ij} + B_{ij}) \).

Compute arrivals-only runway saturation capacity, \( C_{arr} \).

Step 8: Compute expected value of Departure-Destination Matrix \( (\epsilon_{ij}) E(\epsilon_{ij}) \).

Compute departures-only runway saturation capacity, \( C_{dep} \).

Step 9: Compute gaps for \( n \) departures \((n = 1, 2, ..., 5)\).

Step 10: Compute feasible departures per arrival gap.

Step 11: Compute number of departures per gap, if arrivals have priority.

Compute Departure capacity with arrival priority, \( C_{dep-arr-priority} \).

Step 12: Draw the arrival-departure diagram using points: \( C_{dep-arr-priority}, C_{arr}, C_{dep} \).

Results

This section presents modeling and simulation carried out using fast time simulation software for the major Indian International airport and thereby delay and capacity studies as part of the analysis.

Airport Airside Capacity related Delay

A study on the estimation of airport airside capacity (related to delay) study has been carried out using computer simulation models for major Indian international airports viz. Delhi, Mumbai, Kolkata, Chennai, Bangalore and Hyderabad. Fast time simulation model software SIMMOD PLUS [7] is used for the modeling of airfield and airspace scenario of an airport. The airfield details and airspace routes are incorporated based on the Jeppesen maps and charts as part of the modeling. Modeling is carried out with domestic and international routes. Realistic flight schedules [10] of the respective airports during 2010 are used for the simulation purpose.

As mentioned, airport airside capacity includes the capacity of runway, taxi-path and gates. The results of airport airside capacity studies carried out for major Indian airports are presented in Table-1. (In order to estimate the capacity, more number of operations are introduced using the CLONE option of SIMMOD software. This CLONE operation will introduce cloned operations of existing operations to increase the number of operations).

The delays are presented as average ground delay and air delay for each of the airports. Ground delay refers to the delay when the aircraft is on ground like runways, taxiways and at gates. This can occur between the runway and the gate due to taxiway congestion, runway crossings and separation requirements due to wake turbulence, push back delay, taxi speed variation or waiting in departure queue. Air delay refers to the delay when the aircraft is in air. This can occur due to wind conditions en-route and separation requirements for conflict-free flight in high traffic. The average ground and air delays obtained for the major Indian International Airports are presented in Table-1. If these delays are well within the acceptable average delay of 4 minutes, then the number of movements will be considered as the capacity of the airport. The realistic flight schedules correspond to the busy day of the week for respective airports.

From the Table-1, it can be observed that, the average ground delay and air delay are well within the acceptable average 4 min delay even for cloning cases. Hence, the movements observed with cloning are considered as the capacity of the airport.

Runway Capacity (Related to Delay)

Of all the considered major Indian International airports, Delhi International Airport is found to have more traffic with 603 movements on a busy day of the week. The Delhi International airport has been modeled with 3 Runways viz. 09/27, 10/28 and 11/29. Runway 09/27 is used for arrivals and departures of Domestic aircrafts only. Runway 10/28 is used for the arrivals and departures of international aircrafts only. This modeling and simulation...
was carried out using the SIMMOD PLUS software. The hourly runway capacity obtained using SIMMOD PLUS software is presented in Table-2 along with the notional values obtained from Internet source for the respective airports. It is already mentioned that the average delay for all considered airports is well within the acceptable average 4min delay. The total operations on runway per hour (runway capacity) for Delhi airport using two runways i.e. 09/27 and 10/28 is found to be 41. Table-2 presents the runway capacity for major Indian International airports.

### Runway Capacity Studies (not Related to Delay)

Towards the estimation of runway capacity (not related to delay), required data such as mean arrival rate, mean service rate etc. is gathered from the relevant SIMMOD PLUS application. Based on the algorithm derived using the time space concept, Graphical User Interface Software has been developed in Matlab environment. The procedure to estimate Error Separation Matrix and Buffer Separation Matrix using opening and closing cases (explained in steps 3 and 4) is given in Ref.[1, 8]. The computation of number of departures per gap with arrivals priority (explained in steps 9 and 10) done using Gap Analysis is also given in Ref.[1, 8].

The runway capacity study with an example of Bangalore International Airport (BIAL) is demonstrated below. The technical parameters like aircraft mix, departure-departure separation matrix and Runway Occupancy times are taken from the Bangalore International Airport application in SIMMOD PLUS software [7]. Modeling and simulation is carried out with realistic flight schedules for domestic and international routes using runway RWY 27 for both arrivals and departures.

The typical screen shot with the plot of Arrival Capacity and Departure Capacity is shown in Fig.3. Point A

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### Table-1 : Airport Delay Studies for Major Indian Airports

<table>
<thead>
<tr>
<th>Name of the Airport</th>
<th>Average Delay with Actual Schedules</th>
<th>Average Delay with Cloned Schedules</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ground</td>
<td>Air</td>
</tr>
<tr>
<td>Delhi International Airport (VIDP) RWY 27</td>
<td>3 min 28 sec</td>
<td>0 min 24 sec</td>
</tr>
<tr>
<td>Medium and Heavy Aircraft combination</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Realistic Flight Schedules - 603 movements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>With 2% cloning, 613 movements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chennai International Airport (VOMM) RWY 25</td>
<td>0 min 25 sec</td>
<td>0 min 22 sec</td>
</tr>
<tr>
<td>Medium and Heavy Aircraft combination</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Realistic Flight Schedules - 303 movements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>With 1% cloning, 304 movements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bangalore International Airport (VOBL) RWY 27</td>
<td>0 min 46 sec</td>
<td>0 min 43 sec</td>
</tr>
<tr>
<td>Medium and Heavy Aircraft combination</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Realistic Flight Schedules - 256 movements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>With 45% cloning, 376 movements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kolkata International Airport (VECC) RWY 19L</td>
<td>1 min 30 sec</td>
<td>0 min 3 sec</td>
</tr>
<tr>
<td>Medium and Heavy Aircraft combination</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Realistic Flight Schedules - 391 movements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>With 5% cloning, 412 movements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hyderabad International Airport (VOHY) RWY 27</td>
<td>1 min 45 sec</td>
<td>2 min 8 sec</td>
</tr>
<tr>
<td>Medium and Heavy Aircraft combination</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Realistic Flight Schedules - 299 movements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>With 4% cloning, 311 movements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mumbai International Airport (VABB) RWY 27</td>
<td>3 min 49 sec</td>
<td>0 min 36 sec</td>
</tr>
<tr>
<td>Medium and Heavy Aircraft combination</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Realistic Flight Schedules - 549 movements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>With 4% cloning, 552 movements</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table-2: Runway Capacity (Related to Delay) Studies for Major Indian Airports

<table>
<thead>
<tr>
<th>Name of the Airport</th>
<th>Hourly Airport Runway Capacity Obtained from SIMMOD</th>
<th>Hourly Runway Capacity Obtained from Internet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chennai International Airport (VOMM) RWY 25 Medium and Heavy Aircraft combination</td>
<td>19 (Operations per hour)</td>
<td>25 (operations per hour) [<a href="http://www.indianexpress.com">www.indianexpress.com</a>]</td>
</tr>
<tr>
<td>Bangalore International Airport (VOBL) RWY 27 Medium and Heavy Aircraft combination</td>
<td>26</td>
<td>27 [<a href="http://www.seimens.com">www.seimens.com</a>]</td>
</tr>
<tr>
<td>Kolkata International Airport (VECC) RWY 19L Medium and Heavy Aircraft combination</td>
<td>28</td>
<td>25 [<a href="http://www.hindustantimes.com">www.hindustantimes.com</a>]</td>
</tr>
<tr>
<td>Hyderabad International Airport (VOHY) RWY 27 Medium and Heavy Aircraft combination</td>
<td>23</td>
<td>25 [<a href="http://www.thehindubusinessline.com">www.thehindubusinessline.com</a>]</td>
</tr>
<tr>
<td>Mumbai International Airport (VABB) RWY 27 Medium and Heavy Aircraft combination</td>
<td>34</td>
<td>25 [<a href="http://www.wikipedia.org">www.wikipedia.org</a>]</td>
</tr>
</tbody>
</table>

### Table-3: Runway Capacity (Not Related to Delay) Studies for Major Indian Airports

<table>
<thead>
<tr>
<th>Name of the Airport</th>
<th>Departures Only Capacity (per hour)</th>
<th>Arrivals Only Capacity (per hour)</th>
<th>Combination of 100% arrival and Departures Capacity (per hour) Based on Gap Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delhi International Airport (VIDP) RWY 27 Medium and Heavy Aircraft combination</td>
<td>60</td>
<td>22</td>
<td>22 Arrivals and 21 Departures 43 Movements</td>
</tr>
<tr>
<td>Chennai International Airport (VOMM) RWY 25 Medium and Heavy Aircraft combination</td>
<td>62</td>
<td>23</td>
<td>23 Arrivals and 21 Departures 44 Movements</td>
</tr>
<tr>
<td>Bangalore International Airport (VOBL) RWY 27 Medium and Heavy Aircraft combination</td>
<td>60</td>
<td>22</td>
<td>22 Arrivals and 21 Departures 43 Movements</td>
</tr>
<tr>
<td>Kolkata International Airport (VECC) RWY 19L Medium and Heavy Aircraft combination</td>
<td>60</td>
<td>22</td>
<td>22 Arrivals and 21 Departures 43 Movements</td>
</tr>
<tr>
<td>Hyderabad International Airport (VOHY) RWY 27 Medium and Heavy Aircraft combination</td>
<td>60</td>
<td>22</td>
<td>22 Arrivals and 21 Departures 43 Movements</td>
</tr>
<tr>
<td>Mumbai International Airport (VABB) RWY 27 Medium and Heavy Aircraft combination</td>
<td>61</td>
<td>21</td>
<td>22 Arrivals and 21 Departures 43 Movements</td>
</tr>
</tbody>
</table>
indicates the arrivals only capacity per hour (22). Point B indicates the 100% arrivals + departures, (22, 21). Point C indicates the departures only capacity per hour (60.0).

Similar way, runway capacity studies are carried out for major Indian airports and the results are presented in Table-3. The realistic flight schedules [10], (based on a peak day of the week for each airport), have been used for the simulation.

Conclusions

The airport airside capacity studies have been carried out using the fast time simulation software SIMMOD-PLUS for the major Indian airports. From these airport airside capacity studies, it is observed that the average delay (ground and air) for all major Indian International airports is well within the acceptable limits of average 4 minute delay. Cloning studies (increasing the number of movements by Cloning option) have been carried out to estimate the possible airside capacity within the acceptable limits of average 4 minute delay.

The runway capacity per hour using SIMMOD PLUS software is obtained for all the considered airports and compared with the values obtained from Internet source.

Matlab based GUI is developed for the runway capacity estimation using time space analysis. This runway capacity estimated is nothing but throughput capacity and is not defined in terms of delay. For all the major Indian airports, estimation of runway capacity has been carried out based on the realistic flight schedules and runway occupancy details taken from SIMMOD PLUS application of each of the airport. Gap Analysis has also been carried out to obtain feasible departures in the gap of successive arrivals.

References


7. ATAC, SIMMOD PLUS! Software Version 5.0 and Visual SIMMOD software.


Fig. 1 Components of an Airport System

Fig. 2 Delay as a Function of Capacity and Demand

Fig. 3 Runway Capacity RWY 27 of BIAL for Medium and Heavy Combination