CHAPTER FIVE

STUDY, MODELLING AND ANALYSIS OF AN AIRPORT TERMINAL

5.1. INTRODUCTION

The aviation sector in India is growing rapidly. About 95% of international tourist arrivals are by air. Airports facilitate growth of high-value and perishable commodity trade; 40% of exports and imports in India by value are carried by air. The sector might one day also serve to routinely provide connectivity to remote areas otherwise inaccessible by other modes of transport.

The Indian domestic and international air traffic is predicted to increase by about 20% annually, due to investments from the government and private sector. The investments have been estimated at USD20bn over the next five years and the increase of aircraft numbers is expected to double the number of civilian passenger aircraft in India to 400.

Table 5.1 reveals that the aircraft movements, passengers and freight traffic increased by 30.3 per cent, 38.8 per cent and 13.1 per cent respectively during year ending March 2006 over traffic handled during year ending March 2005 (According to Airport Authority of India website¹).

With more airlines operating in Indian skies and air travel becoming more affordable, the infrastructure facilities at airports have remained grossly inadequate. In metro airport terminals even basic facilities are not of acceptable standards, travelers have to line up for entry and exit and wait for screening of their check-in baggage. At international terminals, the wait for immigration clearance is very long.

¹ Airport Authority of India website, http://aai.aero/AAllmain.jsp
### Table 5.1: Total traffic handled in March 2006 and March 2005

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>MARCH 2006</th>
<th>MARCH 2005</th>
<th>%CHANGE</th>
</tr>
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<tbody>
<tr>
<td><strong>Aircraft Movements (in '000)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>International</td>
<td>17.54</td>
<td>15.27</td>
<td>14.9</td>
</tr>
<tr>
<td>Domestic</td>
<td>65.32</td>
<td>48.30</td>
<td>35.2</td>
</tr>
<tr>
<td>Total</td>
<td>82.86</td>
<td>63.57</td>
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<tr>
<td><strong>Passengers (in Million)</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>International</td>
<td>2.02</td>
<td>1.77</td>
<td>14.4</td>
</tr>
<tr>
<td>Domestic</td>
<td>5.16</td>
<td>3.40</td>
<td>51.4</td>
</tr>
<tr>
<td>Total</td>
<td>7.18</td>
<td>5.17</td>
<td>38.8</td>
</tr>
<tr>
<td><strong>Freight (‘000 Tonnes)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>International</td>
<td>92.98</td>
<td>80.41</td>
<td>15.6</td>
</tr>
<tr>
<td>Domestic</td>
<td>44.91</td>
<td>41.46</td>
<td>8.3</td>
</tr>
<tr>
<td>Total</td>
<td>137.89</td>
<td>121.87</td>
<td>13.1</td>
</tr>
</tbody>
</table>

(Source: Airport Authority of India website, http://aai.aero/AAllmain.jsp).

### 5.2. PROBLEM AND OBJECTIVES

The Cochin International Airport was founded as a green field project about ten years back. Initially there were only a few domestic flights operating from this airport and therefore the available facilities were abundant. However soon the airport became the busiest in Kerala with the operations of many international flights and cargo movements. This has led to a scenario where there is urgent need to synchronize the system and get maximum performance out of it in the short run. In the long run facilities need to be augmented. Decision support systems that could help in solving the above problems are very much required. Simulation has been used for the above as is evident from literature. It is proposed to develop a simulation model of the passenger terminals of the Cochin International Airport with the following objectives.

1. To develop an integrated simulation model that models passenger flow and aircraft schedules.
2. To develop models with capability to determine resource utilization at a high level of detail.
3. To allow planners to see operational constraints and bottlenecks, as opposed to inferring operational limitations through reviewing the statistical reports, graphs and charts.
4) To study the effect of additional flights on Runway capacity (utilization)
5) To find out the requirement of flight parking bays
6) To determine the number of X-ray machines
7) To study capacity required for Heating/Ventilation systems
8) To study the impact of rearranging schedules/passenger arrival patterns and to investigate possibility of additional schedules.
9) To study the problem of deployment of equipment

5.3. METHODOLOGY

The application of simulation involves specific steps in order for the simulation study to be successful. Regardless of the type of problem and the objective of the study, the process by which the simulation is performed remains almost same. Law and Kelton (1991) discuss steps for a simulation study. We have followed similar methodology for our simulation study consisting of following steps.

1. After a system study related to operations at the terminal to obtain operational flow charts, data regarding operation times and resource requirement were found out.

2. Conceptual modeling was done and three classes of models to suit three classes of problems were made.

3. A modelling platform was selected and models were made to get sufficient representation of actual operations. Models developed were verified and validated.

4. Experiments were done on the model by changing various parameters and its effect on utilization of equipments and resources were studied. Inferences were made and results presented.

5.4. COCHIN INTERNATIONAL AIRPORT

Cochin International Airport is a novel venture in the history of civil aviation in India where Government of Kerala, NRIs, Travelling Public, Financial Institutions, Airport Service Providers and others joined hands to float the
company to make this project a reality. This airport has been constructed with state of the art facility to enable any type of wide-bodied aircraft to land.

There are two separate centrally air-conditioned terminals for domestic and international operations measuring a total area of around 0.45 lakhs sq. meters. The integrated cargo complex at the airport is capable of handling perishable/non perishable and dangerous cargo.

Kochi airport is, perhaps, the first airport in the country to have the infrastructure to handle the A-380, the biggest passenger aircraft expected in the near future. An apron capable of handling A-380 was built at a cost of Rs.2.8 crore. Another highlight of this airport is its runway length being 3.4 km, it is one of the longest in the country capable of handling wide-bodied jetliner

5.4.1. Terminal Complex

The Cochin airport consists of two terminals, one for domestic and the other for international passengers. The International Terminal caters to a peak capacity of 800 passengers per hour. Passenger's embarkation and disembarkation is through the aero bridges. Two aero bridges are provided. There are two conveyor belts in the arrival hall for baggage handling. Escalators have been provided to go to the aero bridges on the first floor.

A spacious 6000 Sq. Ft of Duty Free shopping area is available in the arrival hall. Similarly, 1250 Sq. Ft of Duty Free shopping area is also available for departing passengers after customs counter. Shopping complex with moderate number of shops is available.

Arrival hall is located on the ground floor, it has a peak hour capacity of 400 passengers. The passage to the arrival hall is through the escalators. There are 8 immigration counters in the arrival hall. Specific counters are earmarked for foreigners and Indians to expedite the clearing process. The health check is carried out along with immigration check.
Pre-immigration area is provided with facilities such as drinking water and public convenience. The arrival hall has two conveyor belts; these belts have individual flight indication boards to indicate flight number.

Two Customs channels are available for arrival passengers namely Red and Green Channels. The Green channel is also called as Walk through channel, through which arriving passengers without dutiable items can walk through. The Red channel is earmarked for clearance of passengers with dutiable items. There are 10 Customs counters, which include counters for currency declaration, transfer of residence and crew. A block diagram of the international terminal facilities showing its facilities is given in Figure 5.1.

The Domestic Terminal Complex consists of well separated arrival and departure areas with all modern passenger amenities. All domestic flights are handled through this complex. A large shopping complex consisting of 21 shops is situated at this terminal. There are two conveyor belts in the arrival hall.

Figure 5.1: A block diagram of international terminal
5.5. TERMINAL COMPONENTS AND CHARACTERISTICS

Airport landside includes the passenger terminal with all of its components. We consider only functional components, i.e., elements providing services or amenities directly related to a passenger boarding or disembarking an aircraft. Non functional components such as concession areas, rest rooms and telephones are not used as a basis for defining airport landside capacity. The passenger’s perception of the quality and conditions of service of one, or a set of, functional components constitutes the service level. A high level of service may be provided if the airport landside has ample capability to accommodate passengers, baggage and airport visitors. This airport landside capability is, of course, influenced by the capacity (in terms of persons processed per unit of time) of the facilities in the terminal. Capacity can be evaluated for each individual functional component of the airport landside. One or more of these components are likely to become the bottlenecks of landside capacity, i.e., the major constraints on serving additional passengers at the terminal.

5.5.1. Some basic definitions

We define the dwell time as the average time a person spends in a place or in a process.

Peak hour, i.e., a representative hour of busy conditions within a functional component. A peak hour is typically defined from historical records by frequency of occurrence. In fact, it may be the average daily peak hour of the peak month, or the peak hour of the 95-percentile busy day.

Demand patterns, i.e., the number of passengers and characteristics of their behaviour that materially influence the ability of a functional component (or group of components) to accommodate them. For the description of each facility, we will deal with the demand pattern.

We consider the terminal as a set of different facilities or facility components. By facility component we mean a subsystem of a facility. For instance, the check-in counters dedicated to a specific airline are a component of the "check-in" facility.
Facilities are classified as *processing* (e.g., check-in counters), *holding* (e.g., gate lounges) and *flow* (e.g., corridors, escalators).

*Processing facilities:* They process passengers and their luggage.

*Holding facilities:* Areas in which passengers wait for some events (as the check-in opening for a flight, the start of flight boarding, etc).

*Flow facilities:* The passengers use them to move among the landside elements.

*Passenger holding areas* are spaces where passengers move around and wait for flight departures and arrivals. These facilities include lobbies, gate lounges, transit passenger lounges, baggage claim area, the arrival area, the area set aside for ancillary facilities, etc. The number of waiting passengers is a function of the number of aircraft served by the holding area, and their functional characteristics, including capacity and loading factors.

The *total time* spent by a passenger to *cross the terminal building* from its entrance point to the gate is the sum of the waiting and service times in the processing facilities plus the sum of the times required to move from a service station to another. The time required to travel from the curb to the gate is one of the most important measure of service level.

5.5.2. Check-in

The *check-in* operation begins when a passenger enters the queue to obtain the boarding pass and checks his baggage(hand) at the check-in counter, and ends when the passenger leaves the counter area. It has to be noted that the (average) processing time at any particular airport depends on many factors (staff experience, flight market and passenger characteristics) as well as on airline operating policies (i.e., number of active counters). Processing time variance can also be large. Capacity of check-in processing facilities is judged by considering the average service time and by comparing the number of passengers in a terminal holding area with the size of that area.
5.5.3. Immigration

The immigration set up at the airport, works under Ministry of home affairs. The immigration processing of passengers both in International Arrival and Departure are regulated by Foreign Regional Registration Officer, who is of the rank of Deputy Commissioner of Police. He is assisted by Assistant Commissioner of Police. The Process of Immigration is controlled by set of rules and regulations issued from time to time. At International Terminal, Cochin Airport arriving passengers are checked cleared on entry into the Terminal. The number of counters available at International Terminal is: Departure - 6 and Arrival - 8.

Immigration checks comprises of 4 steps:

1. Checking of passport/travel documents to identify the holder and to look for possible forgery etc.

2. To ascertain the eligibility of holder either to leave or enter in the Country as per existing rules and regulations.

3. Computer confirmation in clearing passenger.

4. Health check on behalf of Airport Health Office.

For passengers with all documents correct, this is a straightforward process. When some problems are detected in the documents, it takes longer time for immigration process. Walking speeds and distances from check-in to inspection areas and from arrival gates to the inspection areas determine the distribution of actual passenger arrivals.

Originating passengers must undergo a security-screening operation. For this reason, security-screening areas are often elements of queuing and delay for passengers. The average time required for clearance of a passenger, the variability of that time and the rate of passenger arrival at the security screening area are key variables for its capacity assessment.
5.5.4. Customs

Central Board of Excise and customs, a department of the Ministry of Finance is the agency which regulates the clearance of arriving and departing International passengers through International Terminal under Customs Act, 1962. Rules & Regulations under this Act are revised by the Government of India from time to time.

The commissioner of Customs, Customs House, Cochin - 9 having jurisdiction over the Cochin International Airport is functioning from the office of the joint Commissioner of Customs, Air Customs, Cochin International Airport, Nedumbassery for regulating activities under the Customs Act, 1962 in the entire airport area.

The functions of Customs in passenger terminal include air customs wing for clearance of passengers and baggage, Air Intelligence Unit for Anti-smuggling work, prosecution and COFEPOSA cells.

The number of passengers waiting in the baggage claim depends on the rates at which passengers arrive from the gate and the luggage they possess. In general, the maximum demand levels occur when larger aircraft arrive. The baggage claim area capacity can be measured considering the average time passengers wait to retrieve their checked baggage and comparing the number of people in the claim area with the size of that area.

5.5.5. The level of service

The level of service (LOS) represents the quality and conditions of service of one or more facilities as experienced by passengers. Interrelationships exist among the typical measures of service level such as waiting time, processing time, walking time, and crowding, and availability of passenger amenities for comfort and convenience.

Each component of an airport landside has its own unique operating characteristics and demands; hence it is hard to define service level in a unique way. Research conducted by the IATA on Traffic Peaks led to the need of
standard definitions for evaluating LOS and airport capacity (IATA, 1995). To specify the LOS, a set of letters from LOS =A (best) to LOS =F (unacceptable) are used. In Table 5.2, (from Andreatta et al, 2006) the LOS are described in terms of flow, delays and level of comfort. Note that although the description of each individual service level remains the same, subsystems have different spatial requirements.

Service level targets are important because of their serious implications for airport costs and economics as well as for the "image" of the airport. In fact, maintaining a particular LOS at an airport may contribute to attracting new business and is also a reflection of the local or community's goals.

<table>
<thead>
<tr>
<th>LOS Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Excellent Free flow, no delays, excellent comfort level</td>
</tr>
<tr>
<td>B</td>
<td>High Stable flow, very few delays, high comfort level</td>
</tr>
<tr>
<td>C</td>
<td>Good Stable flow, acceptable delays, good comfort level</td>
</tr>
<tr>
<td>D</td>
<td>Adequate Unstable flow, passable delays, adequate comfort level</td>
</tr>
<tr>
<td>E</td>
<td>Inadequate Unstable flow, unacceptable delays, inadequate comfort level</td>
</tr>
<tr>
<td>F</td>
<td>Unacceptable Cross-flow, system breakdown, unacceptable comfort level</td>
</tr>
</tbody>
</table>

Table 5.2: IATA LOS standards

For estimating the appropriate LOS of a facility, let us introduce the index of service (IOS) that represents the value of some measurable quantity, space or time, associated with that facility. The entire IOS range of values is divided into a set of intervals that correspond to internationally accepted, or airport specific, standards. The facility LOS is determined according to the interval where its IOS falls. For example, the space IOS of a waiting lounge is the number of m$^2$ per person. If it is above 2.7m$^2$ per person, the corresponding LOS is A, if it is between 2.3 and 2.7m$^2$ per person, then LOS =B, etc.
Typically, the IOS of a specific facility, during a specific time interval, can be computed from other data through a simple formula, like the following:

\[
\text{IOS} = \frac{\text{area}}{(\text{AP} \times \text{ADT})} \quad (5.1)
\]

This equation means that the IOS is given by the area of that facility divided by the product of the average number per hour of arriving passengers (AP) at that facility, during the time interval under consideration, times the average dwell time (ADT) spent by a passenger in the facility. The IOS can then be used to obtain the LOS of that facility. For example, if the area in front of the check-in counters is 1500m², the number of passengers arriving at the check-in during a particular hour is 3600, and the ADT is 0.15 h, then the IOS for that facility is 2.78m² per person, which means that the corresponding LOS is A.

5.5.6. Computing dwell times in a processing facility

In this section we present a method to compute the ADT at a processing facility. The input required for this can be extracted from the statistical data that are typically available to an airport manager. The entire day is divided into periods of time having the same length (typically one hour). The output provides, among other things, the LOS of each facility during each period of time. To estimate the ADT spent by a passenger in a processing facility during a given period of time, we discarded the classic queuing theory approach (M/M/s or similar) because it is based on the often unrealistic assumptions that both the average number of AP at the processing facility and the average potential service volume (AS) of that same facility are approximately constant over a significant period of time and that AP is strictly lower than AS. This approach will not be able to take into account the dynamic effects of variations over time of AP or AS. These dynamic effects are too important to ignore.

The approach adopted here uses a deterministic equivalent approximation that exactly follows the evolution over time of AP and AS. Basically, this is a graphical model that computes approximately the total waiting time of passengers, given the cumulative arrival function at the processing facility and
the service rate for each time period. This approach was initially proposed by Newell (1971). In this approach the dwell time for each processing facility is estimated by considering the passenger arrival profile and the profile of the number of passengers served, as functions of time.

For each flight, the passenger arrival profile (which must be given as input) is a function of time that provides the number of passengers that have already arrived in the system (i.e., the check-in facility). The profile of the passengers who have been served by the system (and therefore have left it) is again a function of time, but it also depends on the number of servers; this profile is not given as input, but can be inferred from the number of servers which are open and from the mean service time. The number of servers opened by a given air carrier is sometimes conditioned upon the carrier's target LOS standards.

Let \( A(t) \) be the number of passengers that have arrived at the facility up to time \( t \), and \( D(t) \) the overall number of passengers that have already left the facility by time \( t \). \( A(t) \) and \( D(t) \) are non-decreasing functions.

Passenger profiles can be properly approximated by piece-wise linear functions with time on the horizontal axis and the number of passengers on the vertical axis. Furthermore, the combined arrival profiles of the passengers of all flights assigned to the same check-in counter (or block of counters) can be summed up by using the arithmetic of piece-wise linear functions, thus producing an "overall piece-wise linear profile".

Let \( C(t) = A(t) - D(t) \) be the difference of \( A(t) \) and \( D(t) \), i.e., \( C(t) \) represent the number of passengers that are waiting in queue at the facility at time \( t \). In Figure 5.2 we observe that a hypothetical \( A(t) \) and \( D(t) \) in the case where a single flight is assigned to a given counter. If a passenger is the \( n \)th passenger to enter the system, then his/her dwell time \( DT(n) \) can be computed as follows, under the natural assumption of a first-in first-out (FIFO) discipline:

\[
DT(n) = D(n) - A(n),
\]

(5.2)
where $A^{-1}(n)$ and $D^{-1}(n)$ are the inverse functions of $A(t)$ and $D(t)$. Since $A(t)$ and $D(t)$ are piece-wise linear functions, their inverses are also piece-wise linear functions and so is their difference.

![Figure 5.2: Processing facility dynamics (Andreatta et al, 2006)](image)

The above deterministic equivalent approach allows Extend model to compute the averages of many random quantities. In order to compute the variance or other statistical indices for some variables other “tricks” can be implemented (Brunetta et al, 1999). For example, to estimate the upper tail of throughput through a processing facility, the following reasoning may apply. Assuming that throughput follows a Poisson distribution, which, when large numbers are involved can be approximated by a normal distribution, we first establish its mean $\mu$. In the Poisson distribution, the mean and the variance are equal so that the standard deviation is the square root of the variance, $\sqrt{\mu}$. A property of the normal distribution is that (approximately) 95% of all “observations” will be within the limits of the mean plus or minus 2 times the standard deviation. This
means that there is only 2.5% chance that the throughput during any peak period will exceed $\mu + 2\sqrt{\mu}$.

5.6. MODELLING APPROACH

Simulation models of terminal were built in Extend simulation language considering the processes above. Slightly different models are developed for the analysis of the type of problem considered. To address different classes of problem of airport terminals, our modeling effort began at conceptual level. The approach was similar to the cases already we have discussed in Chapters 3 and 4. Three types of models(TYPE 1, TYPE 2 and TYPE 3) were developed.

5.6.1. Model TYPE 1
For such models, the schedule related inputs include and arrival and departure schedules of flights. For output analysis, data for one cycle was repeated for getting statistical confidence intervals. Typically these models were used to study the impact of changes in schedules and operational times. Due to priorities in schedules, these models offer only very little flexibility for studying tactical and strategic decision.

5.6.2. Model TYPE 2
For such models, the schedule related inputs include arrival and departure schedules of flights. These models also have some simulation blocks for giving statistical distributions of wait times, interarrival times instead of schedules for the use of some of the terminal's facilities. For output analysis, data from many cycles were taken for establishing statistical confidence intervals. Typically these type of models were used to study the impact of changes in schedules, operational times and changes in number of some facility. Due to priorities in schedules, these models offer only very little flexibility in some of its blocks for studying strategic problems. More flexibility is available in blocks without specific schedules and priorities. Problems like effect of change in number of x-ray machines on turnaround time for coming months were studied using above model.
5.6.3. Model TYPE 3

Such models totally discard time schedules for arrival and departure of entities. Flight arrivals are generated according to specified statistical interarrival time distributions. Blocks for interarrival and wait time distributions were also attached to various equipments and facilities. Longer term behaviour was checked for output analysis using steady state non-terminating analysis. Typical problems studied using these models include changes in operation times, changes in number of facility and changes in key technology resulting in operational time change.

5.6.4. Basic Model features

Some of the features of a basic model developed are given below. Additional features are added to this model depending upon the type of problem.

5.6.4.1. Input data

The input data for our model are: number of departing flights in the time interval, time of arrival of each flight, aircraft types, flight types, number of passengers on board, passenger arrival profiles (for each flight type), number of counters and service time.

5.6.4.2. Model logic

The model logic is described here briefly. The models follow the flow of passengers in the terminal as well the movement and parking of planes. Flights are generated (separately for domestic and international) according to time schedules when problems related to mainly operational decisions are considered. For this program blocks available in Extend are used. For strategic and tactical problems, the models developed include blocks for empirical distributions or probability distributions and interarrival times were be assigned in these blocks. Flights were given attributes related to its type, parking bay, whether international or domestic, ground time required (later this attribute is converted into activity time required for ground operations) and passenger attributes. Flights wait at airspace for landing (only a restricted number of
airplanes are admitted to the system). After landing, airplanes are taxied to parking bays. Plane arrival and departure processes are shown in Figure 5.3.

Arriving passengers undergo a set of processes depicted in Figure 5.4. (Processes of international and domestic terminals are slightly different). The departing passengers were assigned various attributes of flights, check-in counters, terminal type, gate etc. They undergo the set of processes depicted in Figure 5.5. Both streams (passengers and airplanes) are batched together using a batch block and when all departing passengers have arrived for their corresponding flight, and all ground activities are over, the airplane is taxied to runway and take-off permission is given if runway is free. Only one plane (take-off or landing) is permitted on the runway at a time.

Airport authorities provided the originating passenger percentage. Once total originating passengers per flight were calculated, an arrival time distribution was applied to represent the fact that passengers arrive at various times before their flight. In our models we have generated all flights of a day using Program blocks in which specific schedule times can be given. Domestic and International departing passengers were generated by assigning corresponding Generator blocks, input from a Random Input Block. In Random Input Block, the passenger arrival distributions of domestic and international passengers were given (see Figures 5.6, 5.7 and 5.8 for screen shots of blocks for generation of flight and passengers).

The number of persons arriving at the check-in area could be easily estimated considering the index of the last passenger minus the index of the first passenger arrived at the check-in during the interval under consideration (usually the check-in peak hour). Check-in opening depends on the flight destination. The counter opening policies are discretionary to the airlines. Since this kind of information was not available we made the policy of making available any counter to passengers for strategic problems. Provisions were given in models for operational problems to separate passenger's streams to
designated check-in counters (See Figure 5.9). More screen shots of various parts of the model are given in Figures 5.10 to 5.12.

To estimate the time needed by passengers to move within the building, the terminal is divided into different areas. All passengers held up in last processes or in movement, are not permitted to undergo certain avoidable processes (for example passengers reaching at duty-free at the last moment. In the duty-free shop, passengers spent extra time available for getting duty-free items).

Extend can capture the dynamic nature of many important quantities by displaying them as functions of time in colour graphs. Included among these quantities are: the cumulative number of served passengers, the number of passengers in queue, the number of passengers in queue per counter. The modes also estimated, for each period of interest, the ADT, the average waiting time, and the space and time LOS.

For each passenger facility, the graphs of the following quantities - as functions of time - are provided: facility throughput, i.e., cumulative number of served passengers, number of passengers in queue, number of passengers in queue per counter, number of counters with number of passengers in queue per counter, number of counters with expected queue time. To simplify modelling, we have not separated passengers into passenger classes like business class, economy class etc.
Figure 5.3: Diagram showing plane arrival and departure process
Figure 5.4: Diagram Showing Arrival Process Of International Passengers
Figure 5.5: Diagram Showing Departure Process Of International Passengers
Figure 5.6: International And Domestic flight generators and attributes section in the simulation model

Figure 5.7: International departing passenger generators and attributes section in the simulation model
Figure 5.8: Above show implementation of passenger arrival distribution.

Figure 5.9: Check-in counters: passengers filtered using attributes of flight service (airlines) go through the process of check-in.
Departure of planes

Figure 5.10: A screen-shot of departure of flight's section

Customs checking

Figure 5.11: A screen shot of model blocks for Customs checking and Duty-free shopping for international departing passengers
Figure 5.12: A screen shot of blocks for Baggage processes for arriving international passengers.

5.6.5. Model verification and validation

The models were verified and validated. In the simulation model, the key entities are passengers and airplanes that move through a set of processes and activities that consume resources. We have attached several plotters and information blocks at various flow points in the model. These blocks were used to verify the model. For validation, the graphical procedure similar to the case of Rail Yard was done. Plots of the model results and actual system showed similar behavior for flights and passenger profiles.

5.6.6. Assumptions

1. Cargo movements and cargo flights were not considered

2. Resources like labour (pilots, crew etc) were assumed to be available as required.

3. Ground handling operations and equipment availability was not separately considered.
4. Operations at the Air Traffic Control were not considered except for getting clearance for take-off and landing of flights.

5. It is assumed that all flights coming to the terminal leave as soon as passenger disembarking, ground handling and passenger boarding is over.

6. Delays for flights at the runway, taxiway or parking bays due to reasons other than capacity limitations are not considered (bad weather conditions, fire breakout etc).

5.7. PROBLEMS AND ANALYSIS

Simulation modelling is useful for decisions related to strategic, tactical and operational type decision problems in airport terminal systems. We have developed three types of models helpful in such situations depending upon the problems. Some of the problems related to airport for which simulation modelling were used for analysis and the corresponding model types are given below (Table 5.3).

<table>
<thead>
<tr>
<th>DECISION PROBLEM</th>
<th>MODEL TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strategic level</strong></td>
<td>TYPE 3</td>
</tr>
<tr>
<td>Case 1: Effect of additional flights on Runway capacity (utilization)</td>
<td></td>
</tr>
<tr>
<td>Case 2: Number of parking bays</td>
<td></td>
</tr>
<tr>
<td><strong>Tactical level</strong></td>
<td>TYPE 2</td>
</tr>
<tr>
<td>Case 1: Number of X-ray machines</td>
<td></td>
</tr>
<tr>
<td>Case 2: Estimation of Maximum Occupancy of an Area to Determine Heating/Ventilation System Requirements</td>
<td></td>
</tr>
<tr>
<td><strong>Operational level</strong></td>
<td>TYPE 1</td>
</tr>
<tr>
<td>Case 1: Rearranging schedules/Passenger reporting times to level peak load</td>
<td></td>
</tr>
<tr>
<td>Case 2: Investigating possibility of additional schedules</td>
<td></td>
</tr>
<tr>
<td>Case 3: Deployment of facilities</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.3: Decisions problems and model types
5.7.1 Strategic

5.7.1.1. Case 1: Effect of additional flights on Runway capacity

Over the last few decades, air traffic has been increasing continuously. As a result, a steady increase of transportation capacity is required. The increasing number of aircraft movements and the size of modern aircraft have reduced the capacity reserves of the whole air traffic system up to its limits. But not only the airspace is of limited size and capacity, major airports are becoming more and more a bottleneck for air traffic flow. Since they are nodes (starting point and destination) in the air traffic route network, traffic density in the vicinity of an airport is high and concentrates during the approach and departure process. The problem of capacity limitations also exists on ground due to a confined runway, taxiway and apron system. It continues for the ground handling capabilities as well as for the terminal and passenger management. Often only limited infrastructural changes to airports are possible due to societal, economical and ecological reasons. Capacity in terms of the number of aircraft movements or amount of passenger transportation is not only limited by the airport infrastructure but also by the human operators who have to keep the airport system running. In such an environment, where safety has to be maintained by human beings, operators have to work under high workload.

Total aircraft movement traffic trends for year ending March 2006 at Cochin International Airport (CIAL) is given below (in '000).

<table>
<thead>
<tr>
<th>MARCH 2005</th>
<th>MARCH 2006</th>
<th>% CHANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.61</td>
<td>1.97</td>
<td>21.8</td>
</tr>
</tbody>
</table>

Total passenger traffic for year ending March 2006 at Cochin International Airport (CIAL) is given below (in million).

<table>
<thead>
<tr>
<th>MARCH 2005</th>
<th>MARCH 2006</th>
<th>% CHANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.13</td>
<td>0.17</td>
<td>27.0</td>
</tr>
</tbody>
</table>
Airports are very complex systems with many influences and several stakeholders like the airport operator itself, ATC providers, airlines, ground handling services and others (Sven Kaltenhauser, 2003).

Bazargan et al (2002) mentions that airport’s capacity is its ability to handle a given volume of traffic (demand). Congestion occurs when demand approaches or exceeds capacity. 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, Runway System Capacity, as 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. The Runway System Capacity is primarily dependent on the runway occupancy times of, and separation standards applied to successive aircraft in the traffic mix. Other key items affecting runway capacity include: availability of exit taxiways, especially that of high speed exits that help minimize runway occupancy times of arriving aircraft; aircraft type/performance; traffic mix; Air Traffic Control (ATC) and wake vortex constraints on approach separation; weather conditions [Visual Meteorological Conditions (VMC)/Instrument Meteorological Conditions (IMC)]; spacing between parallel runways; intersecting point of intersecting runways; mode of operation, i.e., segregated or mixed.

Practical Capacity: is defined as the number of operations that can be accommodated in a given time period, considering all constraints incumbent to the airport, and with no more than a given amount of delay. On a typical delay curve, this may be depicted as in Figure 5.14 (Raguraman, 1999).
Capacity Estimation Models: A distinction between analytical and simulation models may be made based on the methodology used to compute capacity, delay or other such metrics. Analytical models are primarily mathematical representations of airport and airspace characteristics and operations and seek to provide estimates of capacity by manipulation of the representation formulated. These models tend to have a low level of detail and are mainly used for policy analysis, strategy development and cost-benefit evaluation (Odoni et al., 1997). Earlier analytical models generated to estimate runway capacity such as that proposed by Harris (1972).

Our models of airport are helpful in providing sufficient information related to occupancy of runways, with a given flight arrival pattern. The runway utilization is related the number of flights, arrival and departure schedules, number of parking bays available, efficiency of ground handling, time required for arrival of all passengers for each flight, time required for departure of all passengers from a flight, delays due to airspace limitations etc. The model has the limitation that it does not consider airspace or ground handling limitations explicitly. However since the model has integrated terminal side operations, the changes in capacity (for additional flights) can be checked simultaneously with bottlenecks in terminal side. For the following analysis we assume that there are no delays due to capacity problems at the terminal side.
A discrete-event plotter attached to the plane arrival section in the model of airport would give us how plane arrivals are distributed over time (see Figure 5.14). Peak rate of plane arrivals can be computed from this plot. For example, circled area shows steepest changes in arrival rate. The peak rate = \((15-9)/(615-515)) \times 60 = 3.6\) arrivals per hour. Average rate of plane arrivals = \(38/24\) = 1.5 arrivals per hour.

![Figure 5.14: Discrete-Event Plotter attached to the plane arrival section in the model of airport would give us how plane arrivals are distributed over time.](image)

We have attached **Timer blocks** to airplanes entry and exit points in the model to estimates values of average turnaround times of planes. The turnaround time is the time taken for a flight from its arrival to take-off. The turnaround time includes time for landing, ground handling, passenger disembarkation, boarding and any delay due to facility constraints. When time and resources for landing, ground handling, passenger boarding etc are kept same for each experiment, the changes in value of turnaround time is indicative of delays due to capacity limitations. Table 5.4 shows the results obtained from experimenting with the model with a single runway facility, by sensitizing the values of aircraft arrival
rate per hour. The experiment is repeated on the model with an augmented runway, other conditions remaining the same. Figure 5.15 indicate that the airport with a single runway could not handle an aircraft arrival rate above 3 per hour on average—if turnaround time at runway is to be kept below 60 minutes. When this facility configuration is changed to two runways (without changing other facilities like parking bays), the improvement is marginal.

<table>
<thead>
<tr>
<th>AIRCRAFT ARRIVAL RATE PER HOUR</th>
<th>AVG. TURNAROUND TIME IN MINUTES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>One runway</td>
</tr>
<tr>
<td>1.6</td>
<td>54.6</td>
</tr>
<tr>
<td>1.7</td>
<td>54.5</td>
</tr>
<tr>
<td>1.8</td>
<td>53.5</td>
</tr>
<tr>
<td>2.0</td>
<td>54.0</td>
</tr>
<tr>
<td>2.2</td>
<td>54.0</td>
</tr>
<tr>
<td>2.4</td>
<td>54.8</td>
</tr>
<tr>
<td>2.7</td>
<td>56.6</td>
</tr>
<tr>
<td>3.0</td>
<td>60.0</td>
</tr>
<tr>
<td>3.4</td>
<td>86.3</td>
</tr>
<tr>
<td>4.0</td>
<td>198.3</td>
</tr>
</tbody>
</table>

Table 5.4: Aircraft arrival rate Vs. Avg. Turnaround

Figure 5.15: Plot of Aircraft arrival rate Vs. Avg. Turnaround time

5.7.1.2. Case 2: Number of parking bays

At present the airport uses 10 parking bays. Out of these 10 parking bays 2 are reserved for big planes like A-330, B-777. Major types airplanes and present
weekly schedules are given in Tables 5.5 and 5.6. When these slots are free, more international planes are also accommodated in these bays due to the availability of aero bridges (we call it Type 2 bays and other bays Type 1 bays).

\[
\begin{array}{|c|c|}
\hline
\text{TYPE} & \text{SCHEDULES} \\
\hline
\text{A-300} & 32 \\
\text{A-319} & 11 \\
\text{B-737} & 28 \\
\text{B-777} & 10 \\
\hline
\end{array}
\]

**Table 5.5: International Sorted According To Type Of Aircraft**

\[
\begin{array}{|c|c|}
\hline
\text{TYPE} & \text{SCHEDULES} \\
\hline
\text{A-320} & 47 \\
\text{ATR} & 42 \\
\text{B-737} & 35 \\
\text{D-228} & 6 \\
\hline
\end{array}
\]

**Table 5.6: Domestic Sorted According To Type Of Aircraft**

The number of parking bays required for parking the arriving planes till its departure depends on

a) arrival rate of planes

b) the parking time

c) the preference on type of bays

In the following experiments we have used Taguchi Methods (for a discussion on use of Taguchi methods in simulation see Dooley and Mahmoodi, 1992). We have kept the parking times based on present patterns and varied the other factors for different levels of bays. We have used Taguchi L12 orthogonal arrays for the following experiments (See Table 5.7 for factors and responses).
### FACTORS AND LEVELS

<table>
<thead>
<tr>
<th>Number of type 1 bays</th>
<th>Number of other bays</th>
<th>Arrival rate</th>
<th>Proportion of type 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>8</td>
<td>3</td>
<td>.75, 0.25,</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>4.5</td>
<td>0.90, 0.40</td>
</tr>
</tbody>
</table>

### RESPONSES

1) Avg wait for bays  
2) Avg delay time of flights

Taguchi Orthogonal Array Design: L12(2**5)  Factors: 5, Runs: 12  
Table 5.7: Factors and responses in Taguchi L12 experiment.

Plots for mean and s/n ratio for max wait time at bay 1 (Figures 5.16a-b) indicate that maximum wait time for type 1 bays is influenced largely by the number of type 1 bays available and the arrival rates of flights and that the little variation in the proportion of requirements of these bays will not produce a large effect on wait times.

Plots for mean and s/n ratio's of average delay of flights (Figures 5.17a-b) indicate that in order to meet the increasing demand for accommodating more flights, there is a need to augment type 1 bays from present number of two to three.
Main Effects Plot for Means

Figure 5.16 a

Main Effects Plot for S/N Ratios

Figure 5.16 b

Figure 5.16 a-b: Effect Plot for Mean and S/N Ratio's Of Average Wait time For Bays
Figure 5.17 a
Main Effects Plot for S/N Ratios

Figure 5.17b

Figure 5.17a-b: Effect Plot for Mean and S/N Ratio's Of Average Delay of Flights
5.7.2. Tactical level

5.7.2.1. Case 1: Number of X-ray machines

X-ray machines are located inside the terminal near the entry point of passengers. This is a critical resource, and if sufficient number of x-ray machines is not available, it could lead to

1) Undesired large queues in the area.
2) Passengers delayed for subsequent processes
3) Delayed flights
4) Reduced level of service

The number of x-ray machines required depends on

1) The time required for processing each baggage
2) Peak hour arrival rate
3) Number of baggage each passenger brings
4) Space available for waiting for this service
5) Level of service

The X-ray machines at CIAL, could handle about 250 bags per hour. However this time is dependant on the type of baggage. Some baggage are easily inspected. If objectionable material is found in a bag, the inspection could take a longer time. We have used triangular distribution based on data collected from actual operations, in our models with given minimum, maximum and most likely times for x-ray machines per baggage.

The number of bags a passenger brings varies from person to person. A proportion of passengers do not bring any bag at all except their hand bags which are not usually inspected at the main X-ray machines. The proportion of passengers with no bags, one bag, two bags, three bags etc were obtained from past data. A typical proportion is shown in Table 5.8.
The number of passengers handled within a stipulated time is important in deciding the X-ray machines because passengers usually report 3 hours before their flight, and there should be sufficient number of machines to handle this load so that all passengers finish X-ray baggage checks within one hour.

**A Deterministic method to find the number of X-ray machines:**

Here we present a deterministic method to estimate the number of X-ray machines and show our modelling can supplement useful information in this. The method is similar to Leone and Liu (2005), but for the determination of ADPM discussed below we show that simulation model we have developed is useful.

The X-ray capacity should be based on peak hour load. The planning day should be the average day of the peak month (ADPM), which represents the most common method of converting planning statistics to a daily and ultimately to an hourly demand baseline (US Department of Transportation, 1988). The determination of ADPM requires the identification of the peak month for the facility under consideration. Most common peak months are July and August. The next step is to identify an average day demand profile for the peak month. This is typically calculated by dividing the peak month demand by the number of days in the peak month. Additionally, the peak hour in a planning day can be calculated based on the actual flight schedule for the ADPM. Typically, large airports have peak hour volume of 10-20% of the daily volume.

### Table 5.8: Number of Baggage per Person

<table>
<thead>
<tr>
<th>NUMBER OF BAGGAGE</th>
<th>% OF CHANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

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The following groups of variables apply in the formula:

Demand parameters: $P$ is the planning hour passenger volume (people per hour), $T$ is the percentage of passengers that do not have checked baggage, $K$ is the percentage of passengers to represent selectees, whose bags require more intense screening, $r$ is the demand scale factor (DSF) between 1 and 1.4 to account for variability of arrival rate through the planning hour, $B$ is the number of checked bags per passenger, and $L$ is the effective demand on the CBS (checked baggage screening) system.

CBS parameters: $S$ is the service rate of the machines (bags per hour) and $F$ is the CBS utilization factor—typically lying between 0.80 and 0.95. This multiplier represents the utilization factor for both the equipment and the screening staff. It is essential in the design that the equipment and staff is not designed to operate on full capacity. This factor accounts for equipment breakdowns, staffing fluctuations, and other disruptions in the screening process.

The effective hourly load on the CBS system is a function of the peak hour volume, the percentage of passengers with no checked baggage, the percentage of selectee passengers, the number of checked baggage per passenger, as well as, the DSF.

$$N_{\text{EFS}} = \frac{P(1 - T)(1 + K)r \times B}{S \times f}.$$  \hspace{1cm} (5.3)

A method to find peak hour load in a particular day

The graphical capabilities available in the model can be utilized to determine peak load in any given day. Following example illustrates this.

The passenger presentation profiles depend both on the flight type and on how and when the passenger has reached the Terminal. These average profiles have to be collected directly by airport that has observed passenger behaviour for over a year. The model generates the curve of passenger arrivals (see Figure 5.18). This curve is obtained from the discrete-event plotter attached to a
count block at the entry side for passengers' generator. Peak rakes can be obtained by magnifying the steep ascending areas in the plot. See Figures 5.19 and 5.20 for details. The peak arrival rate at x-ray machines = (1035-890)/(360-335)= 5.8 passengers per minute, or 348 passengers per hour for the above plots.

Figure 5.18: The model generates the curve of passenger arrivals. Circles portion shows region of peak arrival rate

Figure 5.19: The circled portion in above plot can be magnified by a magnifier tool available in the DE Plotter
Initially, passenger loads for each flight were computed as the product of the number of available seats, multiplied by a load factor, multiplied by a percentage of the passengers who are originating at the study airport. Load factors were obtained from the airlines. Once the passenger arrival pattern was defined for each flight in the flight schedule, the expected number of passenger arrivals for each 10-min period in the day was calculated. The end result of this process was an expected number of passenger arrivals for each 10-min interval, as shown in Figure 5.21. In the chart, the horizontal line represents capacity (For example capacity per hour per machine is 250 bags. If one person carries on average one bag, then maximum capacity/machine in 10 minutes is $250 \times \frac{10}{60} = 41.66$ passengers. For two machines this capacity is $83.33$ passengers. For a utilization factor of 0.8, this capacity reduces to 66.6 passengers. When expected number of bags per person is 2, this capacity reduces to 33.3). When demand exceeds capacity (i.e., where grey bars are above the line), queues develop.
The queue length depends on a number of factors such as the number of bags per person, uptime's of x-ray equipment, number of equipment, arrival profile of passengers etc. Using the models we have developed, one could catch the variability of these characteristics. The number of bags a passenger carries is given as an attribute of the passenger. This attribute can be assigned with a probability (as shown in figure 5.22). The time required for inspection per bag is given as a probability distribution. The load at the x-ray machine varies depending whether it is busy or slack time. A discrete-event plotter attached to the resource pool queue for x-ray machine could reveal the nature of load on the x-ray machine. Figure 5.23 for shows a plot for Average queue length (Average number in the queue. This is a time-weighted average) and Figure 5.24 shows a plot of average waiting times at X-Ray machines (Ave. wait: Average time a passenger waits for the facility).
Figure 5.22: Assigning a baggage attributes and distribution

Figure 5.23: Plot of queue length for X-ray machines
If sufficient number of x-ray machines is not available, it could lead to undesired large queues (indicated by peaks by above plot). Figure 2.25 shows a plot of queue length for the cases of two and three X-ray machines. We observe a considerable reduction in queue length.

Figure 5.25: Shows a plot of queue length for the cases of two and three X-ray machines.
Figure 5.26 shows the effect of number of x-ray machines on average wait per passenger when peak arrival rates are varied. It was observed that three x-ray machines simultaneously deployed could reduce average passenger times at all loads to near zero. Similar results were seen for average queue length (Figure 5.27). The space required for waiting at the X-ray machines could decided based on the equation given in earlier section depending on the LOS.

Figure 5.26: Shows the effect of number of x-ray machines on average wait per passenger when peak arrival rates are varied

Figure 2.27: Shows the effect of number of x-ray machines on average queue length when peak arrival rates are varied
5.7.2.2. Case 2: Estimation of Maximum Occupancy of an Area to Determine Heating/Ventilation System Requirements

For design of the new terminals, or for augmenting present terminal with more facilities, practical issues like requirement Heating, Ventilation and Air Conditioning (HVAC) is of great significance. The specifications for the Heating, Ventilation and Air Conditioning system to serve the central pier of the new building had to be determined to allow sizing of the associated ducts and mechanical rooms. The required capacity of the HVAC system would be determined by the maximum occupancy of the areas served by it, in combination with other factors such as the effects of sun exposure, the potential for air flow between areas, etc. Gross estimates based on the combined capacities of the largest aircraft that could be accommodated on each of the gates on the central pier suggest one range of system loads: other estimation methods suggested lower ranges, and significantly lower costs (Doshi and Moriyamma, 2002)

Simulation models of airport could be used to assess the maximum levels of occupancy in the terminal building. For example A DE plotter attached to the resource pools for international terminal gives the nature of occupancy inside the terminal facilities (Figure 5.28). A max & min block available in GENERIC library of Extend catches the values of maximum occupancy. Table 5.9 shows maximum number of passengers inside the terminal at a time in the cases of 10 and 20 percent of additional passenger arrival (for a particular passenger load profile). Based on the maximum occupancy, capacity may be decided. For the present case, the maximum number of people in the terminal will be 748 from which the air-conditioning and ventilation systems should be designed.

184
Figure 5.28: A DE plotter gives the total number of passengers at a time inside the terminal.

Table 5.9: Maximum number of passengers inside the terminal at a time

<table>
<thead>
<tr>
<th></th>
<th>PRESENT NUMBER</th>
<th>10% MORE</th>
<th>20% MORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total daily Passengers</td>
<td>2468</td>
<td>2714</td>
<td>2961</td>
</tr>
<tr>
<td>Max number in the terminal at a time</td>
<td>748</td>
<td>865</td>
<td>958</td>
</tr>
</tbody>
</table>

5.7.3. Operational

5.7.3.1. Case 1. **Rearranging schedules/Passenger reporting times to adjust peak load**

The simulation model for operational problems can be used to effectively utilize available resources on a day to day basis. For example the queue at x-ray machine could be levelled by changing the timing of passenger load. This is illustrated below. Assume the international departing passenger load of a day is known and as given in Table 5.10. Passengers usually report 3 hrs before international flights.
<table>
<thead>
<tr>
<th>FGT</th>
<th>PLANE TYPE</th>
<th>ARR TIME</th>
<th>GROUND TIME</th>
<th>ARR PASS NUMBER</th>
<th>DEP PASS NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>AI 690</td>
<td>A-310</td>
<td>175</td>
<td>40</td>
<td>89</td>
<td>134</td>
</tr>
<tr>
<td>IC 976</td>
<td>A-320</td>
<td>205</td>
<td>40</td>
<td>65</td>
<td>37</td>
</tr>
<tr>
<td>WS 1127</td>
<td>A-320</td>
<td>255</td>
<td>60</td>
<td>135</td>
<td>71</td>
</tr>
<tr>
<td>AI 956</td>
<td>A-310</td>
<td>300</td>
<td>60</td>
<td>65</td>
<td>9</td>
</tr>
<tr>
<td>GF 270</td>
<td>A-320</td>
<td>355</td>
<td>55</td>
<td>126</td>
<td>121</td>
</tr>
<tr>
<td>WY 827</td>
<td>B-737-8/7</td>
<td>390</td>
<td>60</td>
<td>143</td>
<td>150</td>
</tr>
<tr>
<td>IX 434</td>
<td>B-737-800</td>
<td>515</td>
<td>110</td>
<td>166</td>
<td>91</td>
</tr>
<tr>
<td>EK 530</td>
<td>B-772LD</td>
<td>525</td>
<td>95</td>
<td>346</td>
<td>327</td>
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<tr>
<td>IX 454</td>
<td>B-737-800</td>
<td>535</td>
<td>80</td>
<td>128</td>
<td>147</td>
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<tr>
<td>QR 264</td>
<td>A-319</td>
<td>555</td>
<td>80</td>
<td>145</td>
<td>134</td>
</tr>
<tr>
<td>SV 775</td>
<td>B-777-200</td>
<td>595</td>
<td>120</td>
<td>255</td>
<td>268</td>
</tr>
<tr>
<td>AI 912</td>
<td>A-310</td>
<td>695</td>
<td>85</td>
<td>210</td>
<td>193</td>
</tr>
<tr>
<td>IX 378</td>
<td>B738</td>
<td>1045</td>
<td>50</td>
<td>126</td>
<td>150</td>
</tr>
<tr>
<td>G9 425</td>
<td>A-320</td>
<td>1125</td>
<td>45</td>
<td>173</td>
<td>162</td>
</tr>
<tr>
<td>UL 167</td>
<td>A-320</td>
<td>1130</td>
<td>105</td>
<td>77</td>
<td>28</td>
</tr>
<tr>
<td>IC 595</td>
<td>A-300</td>
<td>1150</td>
<td>55</td>
<td>51</td>
<td>114</td>
</tr>
<tr>
<td>IC 973</td>
<td>A-320</td>
<td>1215</td>
<td>50</td>
<td>74</td>
<td>103</td>
</tr>
<tr>
<td>IX 447</td>
<td>B-737-800</td>
<td>1285</td>
<td>80</td>
<td>61</td>
<td>192</td>
</tr>
</tbody>
</table>

Table 5.10: International departing passenger load of a day

Figure 5.29 shows the plot of International passenger arrivals, all arriving 3 hrs before departure of corresponding planes. Figure 5.30 shows the corresponding cumulative plot. Figure 5.31 shows the DE plot of the same obtained from the model. Note the extreme rush of passenger arrival during the time period 175 minutes to 415 minutes. During this time a total of 1117 passengers arrive. Due to this early morning rush should handle about 280 passengers per hour.

By running the model the queue length at x-ray machine is shown in Figure 5.32. We could see a heavy queue formation (above 300 passengers maximum queue length for both x-ray machines together and avg. wait time 20.59 minutes, avg. number 31.76). Obviously such long queues are not desired. If passenger load could be re-arranged, this queue could be drastically reduced (low utilization period of x-ray machines may be used for this). Figure 5.33
shows the queue length after rearranging passenger arrival for at 175, 210 and 335 minutes. These passenger may be told to arrive half an hour or so earlier then the result is a much reduced maximum queue length and average wait time (i.e., less than 100 passengers as depicted in Figure 5.33).

![Plot of variation in passenger arrival](image)

**Figure 5.29**: Plot of international passenger arrivals, all arriving 3 hrs before departure of corresponding planes

![Cumulative number of departing passengers](image)

**Figure 5.30**: Plot of cumulative international passenger arrivals, all arriving 3 hrs before departure of corresponding planes
Figure 5.31: Plot obtained from the model by allowing international passengers arrive one by one before 3 hrs (up to one hour before departure of plane)

Figure 5.32: Plot showing queue build at X-ray machines in international terminal when passengers arrive one by one before 3 hours of flight departure
Figure 5.33: Plot showing queue build up at X-Ray machines in International Terminal when passengers are told to arrive at a slightly rearranged times keeping the flight schedules same.

5.7.3.2. Case 2. Investigating possibility of additional schedules

The simulation model for operational problems offers good graphical tools for investigating the possibility of permitting additional schedules by airlines. DE plotters are great tools for analysis here. For example plots in Figure 5.34 show the arrival and departure times of planes for a particular day.

It is good to plan additional schedules during the slack periods of planes arrival or departure. Availability of all resources including run ways, parking bays, terminal facilities etc are required to be checked before finalizing a time for arrival and departure of a plane. Again DE plotters can be effectively used here. For example Figure 3.35 shows a DE plot of the number of passengers inside the terminal (excluding that of security lounge) waiting for some service or engaged in some service. The service may be x-ray checking, emigration checking, customs, duty paid shopping etc. Whenever possible, additional schedules may be planned during the slack times of such activities.
Figure 5.34: Plot of arrival and departure of international planes for a particular day.

Figure 5.35: Plot showing the total number of passengers in international terminal excluding the security lounge, and queue at X-Ray machines.
5.7.3.3. Case 3. Deployment of facilities

For daily deployment of facilities, simulation models are useful. Characteristic plots prepared from suitable experiments on the models could be used for immediate decision making. Figure 5.37 and 5.38 gives two such plots. In first case, we have varied the peak arrival rate and studied the number of passengers handled by x-ray machines in one hour. The black line on top represent arrival rate. We could find that we could manage one x-ray machine for maximum arrival rate up to about 150 passengers per hour. Beyond that more machines are required. Only 3 x-ray machines could handle this load without much waiting. In second case passengers handled is plotted, keeping arrival rate of passengers the same and varying number of bags per passenger. It shows that more number of x-ray machines is to be deployed depending on the flights in which passengers are expected to carry more bags with them.

Figure 5.36: Effect of number of X-ray machines on number of passengers serviced in one hour
5.8. CONCLUSION

In this chapter we have presented the use of simulation modeling to study strategic, tactical and operational problems related to an airport. Under strategic problems we have considered the effect of additional flights on runway capacity. We have found that the airport with a single runway will not be able to handle an aircraft arrival rate above 3 per hour on average-if aircraft turnaround time at runway is to be kept below 60 minutes. When two runways were used (without changing other facilities like parking bays), it was found that the improvement was marginal. For the problem of deciding the number of parking bays, our analysis show that in order to meet the forecasted demand for accommodating more flights, there is a need to augment type 1 bays from present number of two to three.

Determination of number of X-ray machines required is one of the tactical problem discussed. The analysis shows that three x-machines simultaneously deployed could reduce average passenger wait times at given loads to near
zero. Another problem considered is the estimation of maximum occupancy of an area to determine Heating/Ventilation system requirements. A DE plotter attached to the resource pools for international terminal gave the nature of occupancy inside the terminal facilities. This number and its variability could be used for designing heating/ventilation systems. For the case presented, there should be a maximum of 748 persons inside the terminal for which the heating/ventilation system should be designed.

Under operational problems we have discussed the case of re-arranging schedules/passenger reporting times to level peak load. From the DE plotters we have observed a heavy queue formation at X-ray machine on a particular day. The model was used to test rearranged schedules to reduce queue. The model was also used to deciding shift timings, preparing pit schedules. The simulation model for operational problems offers good graphical tools for investigating the possibility of permitting additional schedules by airlines and assigning x-ray machines to flight.

In some case (Problems in 5.7.1.1 & 5.7.2.1) simulation is used for supporting analytical methods. Use of Taguchi's design of experiment is illustrated in 5.7.1.2. For long term and medium term decision problems (5.7.1.1 & 5.7.1.2) models developed are less tight on schedules. From the problems (5.7.1.1, 5.7.1.2) it is evident that bottlenecks in some of the facilities (for example less number of Type 1 bays) lead to under-utilization of major facilities like runway. In order to fully utilize strategic fixed facilities like the bottlenecks in other facilities like machines and equipments must also be removed. Further this work illustrates the use of DE plots in a number of situations ((5.7.1.1, 5.7.2.1, 5.7.3.1, 5.7.3.2).