AIR TRAFFIC ANALYSIS AT BANGKOK INTERNATIONAL AIRPORT

Toshikazu SHIMAZAKI* and Shihana Sulaiha MOHAMED**

The rapid growth in air traffic at Bangkok International Airport (BIA) causes excessive delays during peak periods. These delays, consequently results in passenger discomfort, fuel waste and disruption of airlines' schedule. At present, the Second Bangkok International Airport (SBIA) is under planning stage to meet the future demand. Thus, the present system should be improved so that it can accommodate the forecasted air traffic demand until the implementation of SBIA. This paper identifies operational problems in air traffic operations and analyzes the traffic condition of busiest runway at BIA by developed simulation model. Improvement measures have been suggested and evaluated. These can be implemented as remedial actions to overcome present operational problems in the airside of the airport.

Key words : Air Traffic, Simulation, Runway Capacity

1. INTRODUCTION

Air traffic has expanded rapidly due to the rising demand of passenger for fast, convenient and comfortable transportation all over the world. Airline ridership increased from 766 million passengers in 1982 to 1,113 million in 1991 worldwide (ICAO(1992)). According to International Civil Aviation Organization (ICAO), air traffic is expected to increase to more than 2.1 billion passengers in 1994. Air traffic in Asia/Pacific Region is expected to rise by an average of 9.1% over the period of 1992-1994 (ICAO(1992)).

Today, with more than three million passengers each day, severe congestion and very costly delays at more than 100 international airports are seen in the world. At present, there are 21 large hub airports experience more than 20,000 plane-hours of flight delay annually and within the next decade 39 airports will exceed that level (TRB(1990)).

Bangkok International Airport (BIA) in Thailand is the hub of South East Asia. BIA was identified by ICAO as 20th busiest international airport based on international commercial aircraft movements in 1990 and 11th place by international passengers (ICAO(1992)).

The increased air traffic to BIA has created a saturation at peak hours. This causes delays which are costly to the airlines due to extra fuel and crew costs, reduced aircraft utilization and patronage growth. Passengers are also subject to excessive delays and inconvenience in the crowded airport terminal. To minimize delays at BIA, it is not possible to expand facilities further, which have already been expanded to its maximum. It is, therefore, necessary to consider the operational improvements to enhance the capacity through application of technology and operational innovations. This paper discusses the development of simulation model to reproduce the real air traffic pattern at the airport in order to introduce various improvement measures and to evaluate them to minimize delays and maximize the system capacity at BIA.

Runway capacity analysis dates back more than two decades. Most of them were concerned with the estimation of aircraft delays using queuing theory, such as the major work done by the Airborne Instrument Laboratory (AIL) under the contract with U.S. Federal Aviation Administration (FAA). The final result was published as a capacity manual, which describes the maximum number of possible aircraft movements (landing and takeoffs) for various runway configurations and the delays experienced at various levels of demand (Newell(1979)). Mixed landing and takeoff runway operations were studied by AIL in 1963. Based on this, a series of airport capacity manuals was developed for FAA.

Delay analysis goes back to the early 1960s. Newell(1979) quoted that the effect of runway use priority rules in mixed operations on aircraft delays was investigated by Pestalozzi in 1964. Airport becomes congested and delays start accumulating whenever demand exceeds 75 to 80% of the available supply (Odoni & Vittek(1976)), and the lengths of the average delay grows at an increasing rate as the ratio of demand to supply approaches 100%. Therefore, Fisher(1989) stated that the solution to the congestion-delay problem is to minimize the ratio of demand to capacity.

There are many elaborated computer simulation models to predict delays which includes data on air traffic movements of the airport. However, these models lacked the generality required for application to other countries and other type of investigations. Thus, those models are not suitable for air traffic analysis under prevailing air traffic conditions in a developing country like Thailand.

2. OUTLINE OF BANGKOK INTERNATIONAL AIRPORT

Thailand has importance in the world of aviation due to its geographical location and fast economical

* Member of JSCE, D. Eng., Associate Professor, Geotechnical and Transportation Engineering Division, Asian Institute of Technology, GPO Box 2754, Bangkok 10501, Thailand. (From August '93, Dept. of Civil Engg., Univ. of Tokyo.)
** M. Eng., Research Associate, ditto.

development, together with rapid growth in tourism. Thailand is the fourth Asia/Pacific country in terms of average annual rate of growth in the number of international scheduled passengers for the period 1985-1990, next to China, Taiwan and Korea (IATA(1992)).

There are 4 international airports in Thailand of all 25 commercial airports, namely, Bangkok (BIA), Chiang Mai, Hat Yai and Phuket. These are operated under the Airports Authority of Thailand (AAT). BIA is the most important airport due to its position in the country's center and in the largest city of the country. Accordingly, the nation's domestic and international air traffic is concentrated at BIA.

International passenger activity at BIA is about 96% of the total nation's volume and the domestic flow is accounted at 80% of total passengers (AAT(1991)). In 1990, BIA handled 73% of Thailand's total domestic and international scheduled traffic (IATA (1992)). BIA was the 7th airport of the Asia/Pacific region in terms of total scheduled traffic, next to Haneda, Osaka, Honolulu, Narita, Hong Kong and Singapore in 1990. The total scheduled passenger traffic to and from Bangkok has doubled from 1985 to 1990. By the year 2000, it is expected to 2.4 times larger than in 1990 according to International Air Transport Association (IATA) Forecasts. The forecast of aviation activity at BIA is illustrated in **Table 1**.

Present commercial service at the airport is provided by 64 international airlines. Domestic service is provided by Thai Airways and Bangkok Airways to 15 domestic cities.

Airport's operations area at BIA consists of the runway, taxiways and aprons (**Figure 1**). There are two runways at BIA; runway 21R\03L and 21L\03R separated by 395 m center to center. Runway capacity is the critical component at BIA. Only one aircraft at a time can use the runway due to the fact that the distance between two runways is less than the standard minimum distance (760 m) recommended by FAA (AAT(1992)).

Runways are shared with the Royal Thai Air Force. Runways 21L and 21R are both equipped with ILS but runways 03L and 03R are not. The commercial airport apron includes dual parallel taxiways for nearly the full runway length on its west side. The commercial aircraft parking apron totals 718,000 m² and is laid out with 68 aircraft parking positions. Two approach controlling methods are in use at the airport; radar and non-radar.

Table 1: Aviation Activity Forecast at BIA

Year	1995	2000	2010
Passenger (10,000 passengers/year)			
International (1)	2018	2797	4290
Domestic	647	936	1548
Total	2665	3733	5838
Air Freight (10000 tons/year)			
International	78.5	133.2	243.2
Domestic	1.6	2.1	3.1
Total	80.1	135.3	246.3
Aircraft Movements (1000 flights/year)			
Passenger			
-International	102.7	132.2	179.9
-Domestic	49.4	64.6	88.5
Freight	4.1	6.1	10.4
Total	156.2	202.9	278.8
Busy Hours			
Passengers/hour			
-International(2)	3400	4600	6600
-Domestic	1600	2000	3000
Operations/hour(3)	38	46	58

Notes: (1) Transit passengers counted once.
(2) For embarking and disembarking.
(3) Only air carrier aircraft.
Source: AAT(1990).

Due to the dynamic growth in air traffic at BIA, forecasts show that BIA will reach its ultimate capacity before the end of this century. Therefore, the need of the Second Bangkok International Airport (SBIA) has been strongly felt by the Government. The proposed location is "Nong Ngu Hao", about 30 km east of Bangkok. It is expected that SBIA would be implemented by the year 2000, when BIA will reach to its saturation. Thus, the present system should be improved so that it can accommodate the increased number of traffic that is expected in near future.

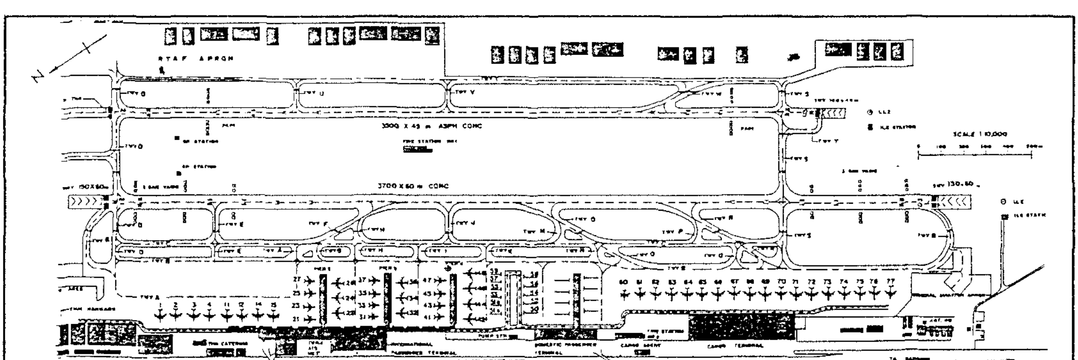

Figure 1: Layout Map of Bangkok International Airport

Table 2: List of Data Collected at BIA

Data on Aircraft Movement (by observation)	General Data (by interviewing)
1. Flight number, type and class of aircraft	1. ATC system and approach control procedures
2. Weather (IFR/VFR) and wind data	2. Number of runways and runway configuration
3. Time of entry to the Bangkok Control Zone	3. Usable runway length and number
4. Time at final approach path	4. Type and location of turnoffs along the runway
5. Approach speeds	5. Operating strategy of runway
6. Estimated time of arrival/ departure	6. Common approach path length
7. Actual Time of arrival/departure	7. Taxiway lengths and names
8. Waiting time for landing/takeoff	8. Number of gates/parking stands
9. Landing/Takeoff speed	9. Gate assignment method
10.Used Runway, taxiway and gate numbers	10.Separation and traffic priority rules in effect
11.Runway occupancy time	11.Aircraft sequencing strategy
12.Waiting time at taxiway	12.Departure/Approach routes
13.Taxiing speed and taxiing time	13.Aircraft classes and landing fee

3. AIR TRAFFIC SURVEY AT BIA

(1) Data Collection

Air traffic survey was executed in order to identify existing operational problems and to obtain the input data for simulation model. Identification of the causes of the problems was mainly done by interview with air traffic controllers and other related officers and observation at the tower and radar operation room for 3 days. Collected major data are shown in **Table 2**. Friday (13th Nov. 1992) and Saturday (14th Nov. 1992) were selected for traffic survey on aircraft movements. Friday is identified as the weekly busiest day of the airport. Saturday was selected to compare the week day and weekend day traffic. Data collection was conducted during peak period from 8.00 hours to 15.30 hours at the control tower and the radar operation room.

(2) Analysis of Survey Data

The survey data were used to compute ultimate runway capacity at the airport by an analytical model in order to compare with the simulation results and were statistically analyzed to obtain distribution parameters of input variables of the simulation model.

The runway capacity defined by FAA (Horonjeff & Mckelvey(1986)), that is, "Runway capacity is the maximum number of aircraft operations that a runway can accommodate during a specified period of time when there is a continuous demand for service" has been utilized in this paper to evaluate the capacity of runway 21R/03L. This definition has been referred to in several ways, such as, "Ultimate capacity", "Saturation capacity" and "Maximum throughput rate". Ultimate runway capacity reflects the capability of the runway to accommodate aircraft during peak periods of activity.

a) Ultimate Runway Capacity by Analytical Method

The analytical model described by FAA (Horonjeff & Mckelvey(1986)) for mixed operations in IFR weather has been used to determine the ultimate capacity. In this model, the capacity of the runway is equal to the inverse of a weighted average of service time of all aircraft. The model treats from the common approach path to the runway. In other words, runway capacity, in operations per hour (takeoffs plus landings), is inversely proportional to the average time interval between successive operations. This average constitutes following four types of average intervals:

i) Takeoff followed by takeoff
ii) Takeoff followed by landing
iii) Landing followed by takeoff
iv) Landing followed by landing

As shown in **Table 3**, percentage of arrivals is almost 50% at BIA. The ultimate runway capacity of runway 21R/03L is estimated as 36 operations per hour at the present operating condition by the analytical model as illustrated in **Table 4**.

b) Statistical Analysis

Statistical analysis of survey data was based on the peak period data. The distribution parameters of observed major data that summarized in **Table 5** were obtained by goodness of fit test.

Table 3: Different Parameters of Air Traffic at BIA

Operation		Aircraft Mix A	B	C	D	Total	% of Arrivals
21R/03L-	Arriv.	5	12	44	128	189	
	Dep.	15	11	52	125	203	
	Total	20	23	96	253	392	48.2
21L/03R-	Arriv.	10	11	6	12	39	
	Dep.	11	2	3	6	22	
	Total	21	13	9	18	61	63.9
Airport		41	36	105	271	453	50.3
Percentage, %		9	8	23	60	100	

Note: A = Light (single engine), B = Light (multi engine , C = Medium, D = Heavy.

(3) Identified Operational Problems

As air traffic demand is reaching the ultimate capacity, aircraft accumulates at several points of

Table 4: Ultimate Runway Capacity of Runway 21R/03L by Analytical Model

% of Arrivals	% of Depart.	Operations Land.	Take.	Total	Avg. Interval sec.
0	100	0	37.5	37.5	96.0
20	80	7.0	30.0	37.0	97.4
33.3	66.7	12.2	24.4	36.6	98.3
50	50	18.1	18.1	36.2	99.5
66.7	33.3	21.7	10.8	32.5	110.7
80	20	24.1	6.0	30.1	119.6
100	0	27.1	0	27.1	133.0

the system to get services. According to the observation of the airside, delays of aircraft occur at the following points.

i) Landing aircraft - at the hold pattern and the end of taxiway to reach gates.

ii) Departing aircraft - at the gate to enter taxiway and the end of taxiway to enter runway.

The following major operational causes of these delays were suspected.

a) Inter-related Operation of Runways

As the separation between the runways at BIA is less than the minimum recommended by FAA, simultaneous operation on both runways is not possible.

b) Separation Rules in Use

The approach radar separation in use is 5 nm for all types of aircraft at BIA. The possible minimum separation is 3 nm according to ICAO separation standards for protection from trailing vortices.

c) Priority Rules in Effect

As arrivals have priority over departures, departing aircraft has to wait longer time to use the runway to takeoff. Queues of departing aircraft were frequently observed at BIA.

d) Less Number of Aircraft Parking (Gate)

Aircraft parking position is a significant element at BIA as in most of cases delays are related with inadequate number of gates.

e) Inadequate Number of Parallel Taxiways

Lack of full-length dual parallel taxiways on both sides of the runways causes inadequate aircraft circulation.

f) Light Aircraft Operating on the Runway 21R/03L

Since light aircraft used for non-commercial activities are allowed to use the runway 21R/03L, system delays increase rapidly and it causes disruption to commercial operations at BIA.

g) Manual Sequencing of Approaching Aircraft

At BIA, the sequencing of aircraft at the final approach path is done manually by air traffic controllers. The perception time required for this task depends on the controller's skill, past experience, age and physical condition.

h) Availability of restricted areas

Runways 21L and 21R are both equipped with ILS where as runways 03L and 03R are not. Operations on runway 03L/21R is complicated due to the presence of prohibited area over the Royal Palace southwest of the airport which limits the length of final approach path. Therefore, radar controllers tend to keep extra mile of separation between arrivals, which reduces the runway capacity.

(4) Improvement Measures

By the simulation model, air traffic at the airport was analyzed to find the optimum operational condition to achieve minimum delay for each traffic operation and maximum capacity of the runway. Evaluated measures are as follow:

a) Separation rules

The approach separation at the airport is 5 nm for all type of aircraft. Present runway capacity can be enhanced by reducing the approach separation.

b) Traffic Priority Rules

The system was tested by allowing aircraft to use the runway on FCFS (First-Come-First-Served) basis, whether it is landing or takeoff.

c) Aircraft Parking Stands

More parking stands can reduce the waiting time of aircraft to reach the gate.

d) Addition of a Parallel Taxiway

The addition of a parallel taxiway can increase the airport's operational efficiency by allowing the runway to realize its maximum capacity by providing adequate aircraft circulation.

Table 5: Parameters of Observed Major Data on Landing and Takeoff

Variable	Average Time, sec	Distribution Type	Parameter
Landing:			
Runway occupancy time	61	Erlang	Alpha=22
Taxiing time	135	Exponential	Mean=135
Waiting time at taxiway	22	Constant	Average=22
Time to reach gate	60	Erlang	Alpha=4
Takeoff			
Push-back time	290	Erlang	Alpha=4
Taxiing time	297	Erlang	Alpha=4
Waiting time for runway	224	Exponential	Mean=224
Runway occupancy time	72	Erlang	Alpha=3

e) Taxiing Speed

Taxiing speed of departing aircraft is slower than landed aircraft. It is possible to increase the runway capacity by higher taxiing speed in takeoff comply with safety requirements.

f) Restricting Light Aircraft

It is suggested to use runway 21R/03L only for heavy and medium aircraft during peak periods.

g) Aircraft Sequencing Strategy for Operations

Installation of computer controlled system to ease the task of controller in sequencing aircraft at final approach path for landing. This will reduce the waiting time at the hold pattern.

4. SIMULATION OF OPERATIONS AT BIA

(1) Structure of the Model

Due to the complexity of air traffic analysis which includes many elements such as aircraft, navigational aids, traffic controllers, separation regulations and weather factors which interact each other in complicated ways, computer simulation by GPSS/PC was selected to analyze the air traffic at BIA.

According to Odoni(1969), 92% of delays occur during the arrival and departure. The developed model describes the movement of an aircraft from Bangkok Control Zone to the gates in the case of landing and from the gates to takeoff in the case of departure. **Figure 2** illustrates the flow chart of developed simulation model.

Major assumptions and input parameters used to formulate the basic case of the simulation model were as follows based on the air traffic survey.

a) Mixed Operation on Single Runway

The simulation model was built to analyze the air traffic movements on runway 21R/03L as a single runway, which is the busiest and longest runway out of two runways (Runways 21R/03L and 21L/03R). Simultaneous operation on both the runways is not possible as the distance between centers of two runways is less than the recommended minimum by FAA. Mixed operations of arrivals and departures were allowed on the runway 21R/03L in the model.

b) Operating Strategy of Runway Use

This simulation model was designed with the ability of changing the operating strategy of the runway (% of arrivals and departures).

c) IFR Weather

The simulation model only dealt with operations conducted under IFR. The statistics at BIA shows that, 95% of operations on runway 21R/03L are conducted under IFR rules (AAT(1991)). Also, delays are primarily associated with IFR as the strict separation standards are in effect.

d) Aircraft Classification

According to the wake turbulence standards based on maximum certified takeoff weight by FAA, heavy (over 300,000 lb), medium (12,500-300,000 lb) and light (12,500 lb or less) aircraft types have been considered.

e) Priority Rules

Landing aircraft was given higher priority than taking off aircraft. Heavy aircraft was given higher priority to leave the gate than medium and light aircraft by considering the larger number of passenger/cargo carried by heavy aircraft.

f) Approach Airways

It was assumed that at a time a maximum of seven aircraft can enter the control zone via seven approaching airways.

g) Hold Pattern

The hold pattern can accommodate four aircraft at a time and other aircraft have to wait away from the hold pattern.

h) Controller's Perception Time

Based on discussions with air traffic controllers at the airport, a maximum perception time of 30 sec. is required by the approach controller in the Radar Room to sequence aircraft at the hold pattern for landing.

i) Weather Effect

The weather effect (ceiling height, visibility and wind data) was not introduced to the model as the model was used to simulate only the IFR condition.

j) Taxiway

A maximum of three aircraft at a time can occupy the taxiway with the consideration of safety due to trailing vortices.

k) Taxiing Distance

An average taxiing distance of each aircraft type was used in the model, but separate values for landing and takeoff aircraft. It was found by statistical analysis that the different taxiing distances according to the location of the gate in the terminal area were not significant.

l) Gates and Gate Assignment

As there are one parallel pier, three finger piers and one domestic parking space, these were considered to be 5 units of gate groups. At a time only one aircraft can enter or start push-back independently at one of these units. Gate assignment for arriving aircraft is done two hours before its expected time of arrival jointly by apron controller and airline and then the gate number is informed to the ground controller. Therefore the model was only concerned up to the time the aircraft reaches the gate.

m) Ground Speeds of Aircraft

This Model was incorporated with following aircraft speeds based on the survey.

i) Landing aircraft - speed in Bangkok Control Zone, at final approach path and taxiing speed

ii) Departing aircraft - taxiing speed

(2) Simulation Procedure

For each scenario a simulation time of 3600 sec. was used. This is to represent the daily peak hour which is considered as the most saturated period due to its coincidence with preferable flight schedule time of the region. Nine repetitions were executed by changing the seed of random number. The present operating condition at BIA was reproduced by the simulation model as a basic case for evaluation of suggested improvement measures. Analysis of variance was performed to evaluate the significance of different improvement measures in comparison with present condition of the airport.

The closer agreement of the model with the actual system of air traffic operation at BIA was validated by following three-step approach.

a) Comparison of simulated results with analytical results.
b) Comparison of simulated results with observations of the system.
c) Acceptance of results by experts (air traffic controllers of BIA and planners of AAT).

The simulation model gives following as its output by each simulation run.

a) Facility

Number of operations per specified time period, utilization and average service time, number of delayed operations on final approach path and runway.

b) Queue

Maximum number of aircraft in the queue and average waiting time at final approach path, taxiway and runway.

c) Transit time of landing and takeoff

Mean transit time and standard deviation of transit time for landing, which is defined as the time required for an aircraft to reach the gate from the time when it approaches Bangkok Control Zone (35 nm) and transit time for takeoff, which is defined as the time required to an aircraft to takeoff from the time when it leaves the gate.

5. RESULTS OF SIMULATION

(1) Capacity of Runway 21R/03L

Using the simulation model, capacity of runway 21R/03L was found as 39 operations per hour for 50% of takeoff split, which represents the existing situation at the airport. The simulated and analytical runway capacity were compared in **Table 6**.

(2) Analysis of Improvement Measures

The improvement measures discussed in section 3.(4) are relatively inexpensive and fairly easy considering the construction plan of SBIA. **Table 7** outlines major parameters of considered improvement

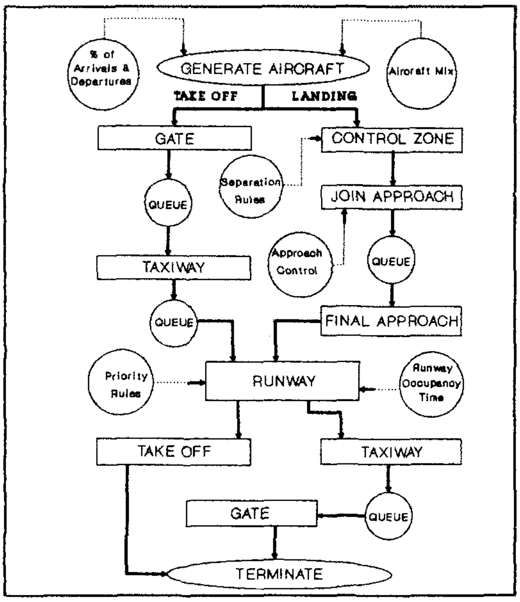

Figure 2: Flow Chart of Developed Simulation Model

Table 6: Ultimate Capacity of Runway 21R/03L

% of Land.	% of Take.	Analytical Model	Simulation Model
0	100	37.5	35.8
33.3	66.7	36.6	42.8
50	50	36.2	39.0
66.7	33.3	32.5	38.4
100	0	27.1	25.6

measures for the simulation model.

Although, in case of implementing any of these improvement measures, additional safety measures would be taken by responsible authorities to ensure a safe and riskless environment in air and on ground at the airside of BIA.

Table 7: Proposed Improvement Measures at BIA

Improvement Measure	Present	Suggested
A. Reduced Approach Separation (nm)	5	4
B. Priority for Runway Use	Landing	Equal
C. Increased Number Parking Stands	5	6
D. Addition of a Parallel Taxiway	3	4
E. Increased Average Taxiing Speed - in Takeoff (knots)		
-Heavy: Medium & Light	20:25	25:30
F. No Medium & Light Aircraft on Runway 21R/03L		
- Heavy: Medium: Light	60%:23%:17%	100%:0%:0%
G. No Light Aircraft Operated on Runway 21R/03L		
- Heavy: Medium: Light	60%:23%:17%	72%:28%:0%
H. Computer controlled Sequencing System		
- Controller's perception Time (sec.)	30	0

Table 8: Overall Evaluation of Improvement Measures

Improvement Measure (1)	Landing Avg.Time,sec.	% Reduced	Takeoff Avg.Time,sec.	% Reduced	Total (A+B)	% Reduced	Rank
Present	1388		1019		2407		
A	1172	15.6	1102	-8.1	2274	5.5	4
B	1534	-10.5	843	17.1	2377	1.2	5
C	1385	0.2	904	11.2	2289	4.9	2
D	1376	0.9	993	2.5	2369	1.6	6
E	1352	2.6	813	20.0	2165	10.1	1
F	1369	1.4	1126	-10.4	2495	-3.7	8
G	1323	4.7	968	5.0	2291	4.8	3
H	1376	0.9	1012	0.7	2388	0.8	7

Note:(1) For coding system of improvement measures, refer Table 7.

For the evaluation purpose, the simulation result obtained at 50% takeoff split was considered for each improvement measure. Following are the two major indexes for the improvement of efficiency and utilization of a runway system.

i) Increment in runway capacity (operations/hr).

ii) Reduction in waiting time and total time saved in operation of aircraft movement on the runway.

Total time saved in operation of an aircraft movement was considered as most effective criteria than the others in evaluating improvement measures and therefore final evaluation was based on this criteria. If the total operation time saved by improvement measures are the same, the increment in the runway capacity was utilized to rank those in comparison with each other. The reduction in waiting time at each described points give an idea of queue length and the level of congestion.

As shown in **Table 8**, improvement measure E, i.e. increased average taxiing speed, was found as the best one out of all the suggested improvement measures.

In addition to testing each improvement measure individually, different combinations of evaluated improvement measures have been also tested, except the addition of a parallel taxiway and the restriction of both medium and light aircraft during peak periods. The result from combinations of these selected improvement measures are shown in **Table 9**.

Table 9: Combinations of Improvement Measures

Improvement Measure	No.of Operations	Waiting Time (sec.) Taxiway	Gate	Hold
Present	39	126	29	9
A	46	263	24	10
B	39	148	11	10
C	40	219	6	9
D	41	29	21	10
E	43	52	7	9
F	39	228	13	15
G	40	181	9	9
H	39	154	5	0
EC	43	59	2	9
EG	39	79	21	10
EA	43	110	12	9
EB	41	160	17	8
EH	40	171	29	0
ECG	43	120	1	9
ECA	45	77	7	7
ECB	44	252	7	9
ECH	44	68	4	0
ECGA	45	66	7	9
ECGB	46	123	5	12
ECGH	42	161	6	0
ECGAB	45	64	3	9
ECGBH	45	27	2	0
ECGABH	42	55	5	0

6. CONCLUSIONS AND RECOMMENDATIONS

The operating strategy of BIA is found by the air traffic survey as 50% arrivals and 50% departures with 60% of heavy, 23% of medium and 17% of light aircraft.

The developed simulation model was validated as an appropriate representation of actual air traffic movement pattern on runway 21R/03L as a single runway at BIA. At present the ultimate runway capacity obtained by the simulation model is 39 aircraft movements per hour at 50% takeoff split.

Following improvement measures, with possible required safety and administrative procedures, have been evaluated using the developed simulation model, as suitable to minimize delays in air traffic operations and to achieve maximum utilization of runway 21R/03L during peak periods. By these improvement measures the ultimate capacity of runway 21R/03L can be increased from 39 operations per hour to a maximum of 46 operations per hour.

(1) Increased average taxiing speed of departing aircraft

This study provides the technical feasibility of increasing the runway capacity by increased average taxiing speed of departing aircraft. It is recommended to conduct a detail survey on taxiing speeds including all type of aircraft at BIA and evaluate the percentage of increase in runway capacity for each 1 knot increment of taxiing speed with the use of the simulation model developed in this study. And finally, the most suitable speed increment can be applied to the system comply with safety requirements.

(2) Increased number of parking stands

This improvement measure was the second best measure to minimize delays at the airport. Under BIA development plan, additional aircraft parking stands are under construction and expected to put in service by the end of the 1993.

(3) No light aircraft operated on runway 21R/03L

It is recommended to restrict light aircraft to use runway 21R/03L during busy hours to accommodate anticipated future demand. This can be implemented by a policy change taken by AAT, such as increasing landing fee for light aircraft during busy hours.

(4) Approach radar separation of 4 nm

To reduce approach radar separation from 5 nm to 4 nm, it is necessary to take required operational and facility development action such as ATC personnel training and installation of a precision runway monitoring system.

(5) No priority to landing aircraft

This measure could be implemented with the conformation of ICAO and with the concern of airlines. This measure will be beneficial to reduce the queue length at the gate.

(6) Computer controlled system to sequence approaching aircraft

Computer controlled automated system was proposed to reduce the perception time required by controllers to sequence approaching aircraft.

The developed simulation model has the ability of analyzing air traffic at any airport of single runway with mixed operation under IFR weather. The sophistication of the present simulation model could be increased by including weather effects to analyze both the IFR and VFR operations at the airport. By including flow control procedures the model could be utilized to investigate interactions of flights in enroute portion. The effect of multiple runways could be facilitated by incorporating the runway assignment and selection rules in the model. Also, it is recommended to study the required modification in the model to analyze the case with installation of microwave landing system (MLS) and related operational aspects. Further refinement of the model could be achieved by incorporating passenger and cargo operations as well as air traffic operations.

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REFERENCES

AAT(1990), Airport System Master Plan Study (ASMPS) Forecast, 1990, AAT.

AAT(1991), Air Transport Statistics at Bangkok International Airport - Year 1991, Technical Division, Planning Department, 1991.

AAT(1992), Bangkok International Airport Aerodrome & Approach Control Training Manual, Air Traffic Control Division, Flight Control Department, AAT.

AIL(1969), Airport Capacity Handbook, Second edition, Dear Park, New York 11729, FAA, June 1969.

Averill M.1 & Kelton W.D(1991), Simulation Modeling and Analysis, McGraw-Hill Book Co., 1991, 348pp.

FAA(1983), Airport Capacity and Delay, Advisory Circular, U.S., DOT, AC No. 150/5060-5, 1983, 91pp.

Fisher J. B.(1989), Managing Demand to Reduce Airport Congestion and Delays, Transportation Research Record 1218, National Research Council, Washington, D.C., pp. 1-10.

Hamzawi S. G.(1992), Lack of Capacity: Exploration of Alternative Solution, Transportation Research, National Research Council, Vol 26A, pp. 47-58.

Horonjeff R. & McKelvey F.(1986), Planning & Design of Airports, Third edition, McGraw-Hill Book Co., 460 pp.

IATA(1992), Bangkok Airport Traffic forecast 1990-2005, June 1992, International Air Transport Association, Montreal - Geneva.

ICAO(1987), Airport Planning Manual - Part 1, Master Planning, Second Edition, Doc.9184-AN/902/part 1, 1987.

ICAO(1990), Airport Traffic 1990, Digest of Statistics, No. 383, Series AT-No.31.

ICAO(1992), ANNUAL REPORT: The State of International Civil Aviation, ICAO Journal, Official Magazine of International Civil Aviation Organization, July 1992, 49 pp.

Newell G. F.(1979), Airport Capacity and Delays, Transportation Science, Vol 13, No. 3, Aug. 1979, pp. 201-241.

Odoni A.(1969), An Analytical Investigation of Air Traffic in the Vicinity of Terminal Areas, Doctorate Thesis, Massachusetts Institute of Technology, 1969.

Odoni A. & Vittek J.(1976), Airport Quotas and Peak Hour Pricing: Theory and Practice, Flight Transportation Laboratory, Massachusetts, Institute of Technology, Cambridge, Mass., May 1976.

Stephen L.M., Hockaday & Kanafani A.K.(1974), Development in Airport Capacity Analysis, Transportation Research, National Research Council, Vol 8, pp. 171-180.

TRB(1990), Airport System Capacity: Strategic Choices, Special Report 226, Transportation Research Record, National Research Council, Washington, D.C., 134pp.