Evaluation of the Runway Capacity of the Ninoy Aquino International Airport

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Abstract: The Ninoy Aquino International Airport (NAIA) is currently experiencing congestion because the demand for operations is greater than the airport's capacity. To solve this problem, this study aims to increase the runway capacity of NAIA. This study was conducted to adjust the current sequence of flights so that more operations may be accommodated per day. With a higher runway throughput, structural projects and expansions will not be necessary to serve current and projected additional flights. Runway use must be systematical in order to lessen delays due to operational procedures that are experienced by travelers. Airport operation rules and analysis on actual observations were applied in order to optimize runway utilization. Algorithms were created in order to generate an adjusted schedule of flights with a higher capacity of 47 aircraft movements per hour, or 7 operations more than the current declared value. The same principle was applied to observed flights; hence the maximum capacity of the runway is now 52 aircraft movements per hour, or 8 operations more than the current maximum capacity.

1. INTRODUCTION

1.1 Background of the Study

Domestic and international airlines are constantly expanding their services and increasing their flights to and from Manila. This results to a higher demand for operations at Manila's airport, known as the Ninoy Aquino International Airport (NAIA). Although some renovations and other upgrades were completed in the recent years, NAIA is still not able to cope with its increasing demand, as evidenced by numerous and frequent reports on flight delays, long queues, and extended waiting periods in terminals. Hence, the airport is said to be experiencing congestion. By definition, airport congestion occurs when the total demand to use airport facilities is greater than the current capacity (Roosens, 2008). Simply put, the capacity of NAIA is insufficient for its demand.

There are two approaches in solving this problem. First, expansion projects will clearly increase the capacity of NAIA. However, due to spatial, time, budget, and environmental constraints, it is more practical to find nonstructural ways, such as maximizing the efficiency of current airport facilities.

The runway acts as the main road or thoroughfare for aircrafts to access an airport, which means that its utilization is very crucial in accomplishing daily flight operations. If the runway conditions are insufficient for the current demand, then it follows that more problems will arise with the addition of more flights. Thus, another solution to alleviate airport congestion is to increase the capacity of the runway in order to handle all flights on time or with minimal delay.

Runway capacity is defined as the ability of a runway to manage operations, which include a mixture of departures and arrivals, in a given unit of time. It is usually measured in number of aircraft movements per hour. As declared by the Manila International Airport Authority (MIAA), the current capacity of the NAIA is at 40 aircraft movements per hour, consisting of commercial flights, cargo flights, and general aviation. This can be stretched to a maximum capacity of 44 aircraft movements per hour during actual operations, depending on the skills and cooperation of both the air traffic controller and the pilots.

The efficiency of the runway system is most crucial in addressing and keeping up with the flights operating in NAIA. There are four factors affecting runway capacity that are significant for this study. These are runway occupancy time, fleet mix, separations, and reaction time of the pilot.

The runway occupancy time (ROT) is the amount of time that a runway is exclusive to an aircraft. The longer it takes for an aircraft to leave the runway means the longer its ROT. A longer ROT postpones the next operation, which then leads to less cumulative number of aircrafts that can be served over a period of time. It is favorable to have a shorter ROT to handle more aircrafts thus increasing the runway capacity.

The next factor is the fleet mix or the percentage of aircraft types operating on the runway. Larger aircrafts have larger engines, so they can operate faster and can leave the runway quicker. Using the same logic, the smaller aircrafts take more time to traverse the runway. By knowing the usual ROT of each aircraft type and the fleet mix, it is easier to estimate the capacity of the runway. Also, a more varied mix signifies a lower capacity compared to a more consistent mix.

Air traffic control rules, specifically the wake turbulence separation rules, affect runway capacity. Enough separation from the leading aircraft is provided to avoid the following aircraft from experiencing dangerous wake turbulence. Separation is either distance-based, expressed in nautical miles, or time-based, expressed in seconds. Larger aircrafts generate wake turbulences that are more harmful to smaller aircrafts. Because of this, more separation is given between larger leading aircraft compared to small aircrafts followed by larger ones. Bigger separation results to a longer time to finish operation and thus lower capacity.

The last factor affecting capacity is the reaction time for each aircraft type. This is the time it takes for a pilot to respond and act on a given command by the air traffic controller. Reaction time is influenced by the mechanical properties of an aircraft. Similar to ROT, the shorter the reaction time means the faster an operation is finished and the faster transition to the next operation.

It is possible to estimate the runway capacity by integrating the above factors into a schedule. Each completed aircraft movement has a corresponding ROT. The number of completed movements over a certain time period gives the capacity of the runway. Immediately after an aircraft ends its operation, ROT starts for the next operation. In an ideal schedule, operations must be accomplished at the minimum ROT for maximum efficiency; however, stalling times and prolonged ROTs are not completely avoided. These cause underutilization of the runway. Through systematic scheduling and sequencing of flights, ROT can still be reduced and the resulting saved time can be consumed by additional flights. More aircrafts are catered and runway capacity is increased. There are regular scheduled flights in NAIA must be accomplished on time, or with no to very minimal delay.

1.2 Problem Statement

Flight delays are one of the biggest problems encountered in most airports around the world, and it is a major concern in the Ninoy Aquino International Airport (NAIA) in Manila. These delays occur when there are multiple demands to use an airport facility at the same time. There is a waiting period and a queue builds up. These indicate that a runway is operating beyond its capacity. Due to constraints in construction projects, nonstructural solutions must be developed and applied to alleviate the problem of congestion in NAIA.

Runway utilization in NAIA must be evaluated to maximize its operation rate. There are improvements that can be developed in order to increase the current capacity and maximum capacity of NAIA.

1.3 Objectives of the Study

This study aims to optimize the use of the runway at the Manila airport by keeping minimum separations between pairs of aircrafts, using RECAT standards for aircrafts. The study will result to an efficient sequence of aircraft movements and an updated capacity of the Manila airport. The objectives of this study are listed as follows:

i. Record the runway occupancy times for both arrivals and departures, as well as the sequence and categories of aircrafts using the runway through actual observations from the Manila Tower;

ii. Devise algorithms to adjust scheduled and observed flights in order to evaluate the effects of rolling time, reaction time, and separation rules on the overall aircraft movements on the runway;
iii. Generate recommendations for air traffic services personnel to follow during actual operations for increased runway throughput and improved schedule reliability;
iv. Give an updated capacity and maximum capacity of the NAIA runway; and,
v. Produce an adjusted and optimized schedule of flights

1.4 Significance of the Study

By focusing on the current runway operations, this study will provide ways to maximize the efficiency and utilization of the airfield capacity of NAIA. When runway capacity is increased, operational delay in NAIA will be solved and expansion projects will not be necessary. Also, for actual operations, the rulebook resulting from this study will guide controllers in conveying the most efficient sequencing of aircrafts. The updated capacity and the targeted maximum capacity of the runway are projected to accommodate more flights at NAIA.

1.5 Scope and Limitations

This study focuses only on the airside capacity of NAIA, specifically the runway. Capacities of other airport components are not measured. Also, this study only addresses the delay resulting from runway operations, such as demand exceeding capacity or ineffective utilization. Other causes of delay are not considered. Analysis was based solely on operations following the summer schedule. Actual time studies were performed only during peak days and peak hours, which were at 2:00-7:00 PM on Fridays, and 08:00-11:00 AM and 1:00-6:00 PM on Saturdays.

1.6 Study Flow

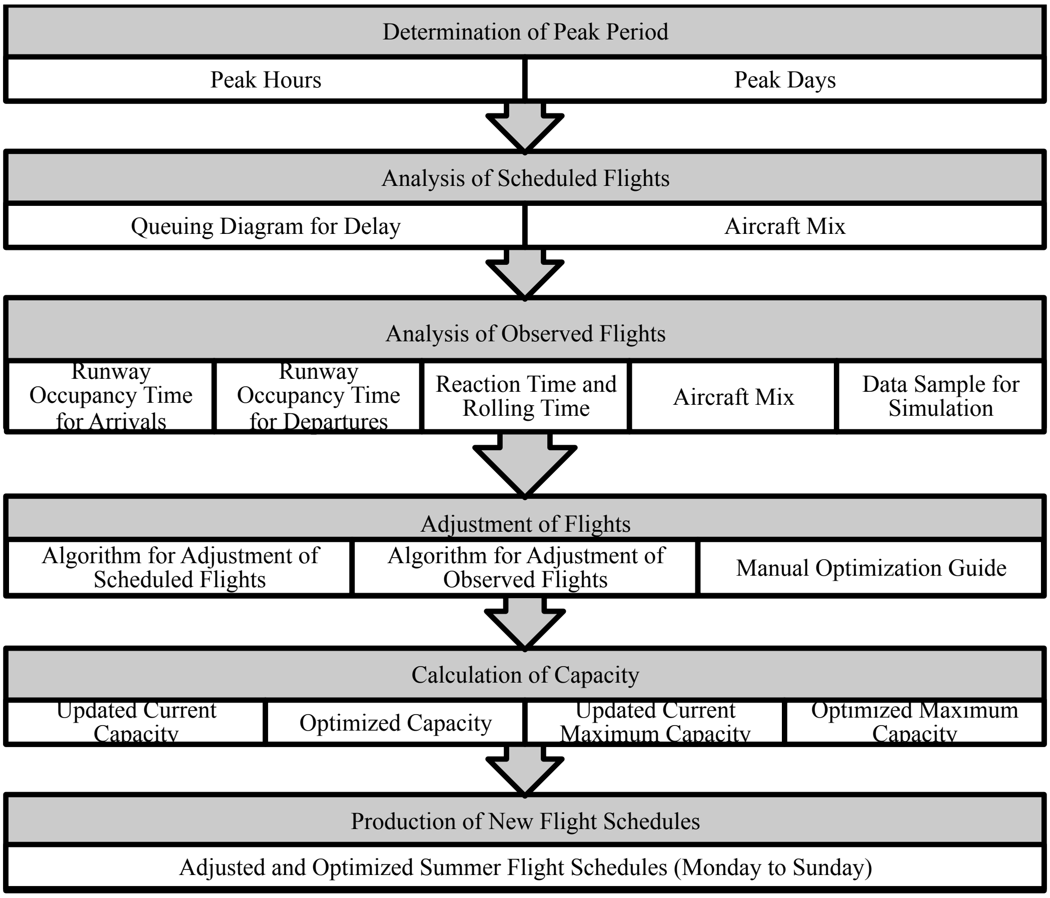

Figure 1. Study Flow

This study is composed of 5 major parts as shown in the flowchart above. The items in the white boxes are the results acquired from each of the major processes.

The peak days and the peak hours in the airport were initially identified for proper scheduling of time studies at the Manila Control Tower.

In order to evaluate the current capacity of the NAIA runway, the complete Summer Flight Schedule and the Passenger and Aircraft Movement Statistics were obtained through the Manila International Airport Authority (MIAA) and the Civil Aviation Authority of the Philippines (CAAP). The number of scheduled flights per hour was tallied and any excess to the declared capacity (i.e. flight counts greater than 40) were considered as delayed aircrafts. These operational delays were illustrated through queuing diagrams. At the same time, the aircraft mix was quantified using the statistics.

Flight schedules only serve as a guide for aircraft operations, such that flight slots are planned to fit the declared capacity of the NAIA runway. During actual operations, pilots and air traffic controllers execute tasks at the safest and fastest possible rate to cut runway occupancy time (ROT). When ROT is further minimized, the capacity is subsequently stretched to its maximum capacity. To evaluate the current maximum capacity of the NAIA runway, actual time studies at the Manila Control Tower were conducted. The runway occupancy time for arrivals (ROTA) and the runway occupancy time for departures (ROTD) were recorded by logging the instantaneous time (noted in UTC) as each aircraft reached predetermined points on the runway. The time logs were also used to calculate the reaction time and the rolling time for each aircraft.

Airport operation rules, parameters, and safety procedures were compiled from documents published by the International Civil Aviation Organization (ICAO) and the European Organization for the Safety of Air Navigation (EUROCONTROL). These became the building blocks of the algorithms used to adjust both scheduled flights and actual flights. Data gathered from planned and actual flights were simulated to calculate the updated capacity and the updated maximum capacity of the NAIA runway. The simulations also resulted to a new and complete Optimized Summer Flight Schedule.

2. TECHNICAL PARAMETERS

2.2.1 NAIA Runway Layout

The plan view of NAIA is shown to scale in Figure 2. Two intersecting runways are available, Runway 06/24, the area filled in orange, and Runway 13/31, the area filled in yellow. Runway 06/24 is 3,737 meters long and 60 meters wide. Runway 13/31 is 1,995 meters long and 45 meters wide. The physical differences limit the type of aircrafts that can operate (depart or arrive) on each of the runways. Due to environmental rules, arrival on Runway 31 is prohibited.

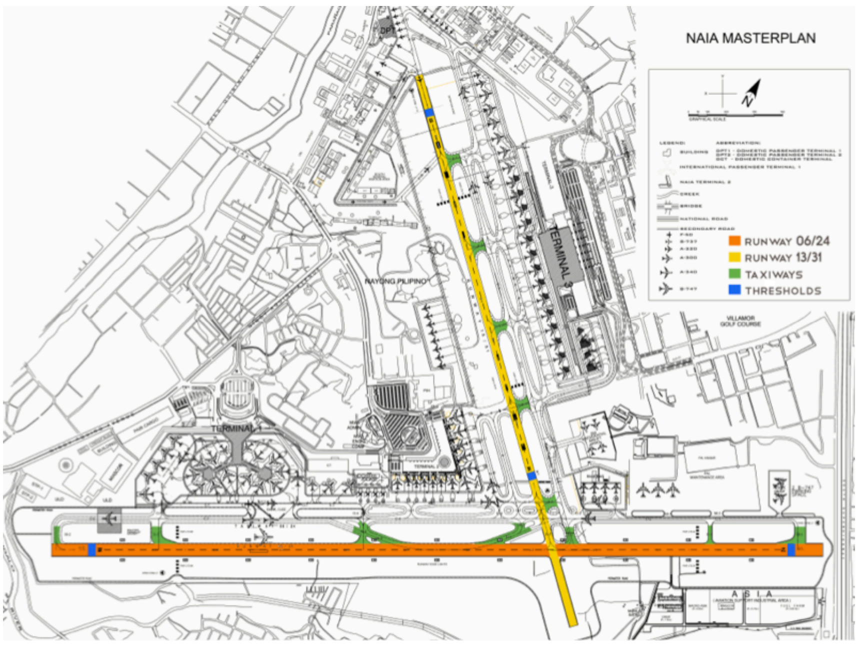

Figure 2. Plan View of NAIA

2.2.2 Aerodrome Code

The Aerodrome Code has six categories based on the wingspan and length of aircrafts. It is summarized in Table 1. This categorization is used to designate which runway an aircraft may use.

Table 1. ICAO Aerodrome Codes

Code	Aircraft Wingspan	Runways Allowed
A	Less than 15 meters	06/24 and 13/31
B	15 meters to 23 meters	06/24 and 13/31
C	24 meters to 35 meters	06/24 and 13/31
D	36 meters to 51 meters	06/24 only
E	52 meters to 64 meters	06/24 only
F	65 meters to 79 meters	06/24 only

2.2.3 Aircraft Categories

The ICAO Document No. 8643 contains three weight-based categories defined, namely Heavy, Medium, and Light. The categories and descriptions are summarized in Table 2. These categories are essential to air traffic controllers in NAIA for them to manage aircrafts safely.

Table 2. ICAO Aircraft Categories Based on Wake Turbulence

Category	Aircraft Weight
Heavy	136000 kg or more
Medium	Between 7000 kg to 136000 kg
Light	7000 kg or less

The current ICAO categories have a wide range of aircrafts. Thus, the properties and separation rules are considered to be very conservative. To resolve this problem, the European Organization for the Safety of Air Navigation (EUROCONTROL) has developed a new classification of aircrafts, called the RECAT, and new separation minima. The formulation of the RECAT was patterned after ICAO. Aircraft types are now assigned into one of six categories, as summarized in Table 3.

Table 3. RECAT: Eurocontrol Aircraft Categories

RECAT	Description	Aircraft Types
A	Super Heavy	A380
B	Upper Heavy	A333, A340, B744
C	Lower Heavy	B763, B764, B783
D	Upper Medium	A320, A321, B737
E	Lower Medium	AT45, AT72, GLF4
F	Light	D328, LJ35, JS32

2.2.4 Separation Minima

Based on the aircraft category of the leading aircraft, there are minimum separation requirements to be followed until the following aircraft can use the runway. The ICAO separation minima expressed in are summarized in Table 4.

Table 4. ICAO Separation Minima in nautical miles

Follow / Lead	Heavy	Medium	Light
Heavy	4	5	6
Medium	3	3	5
Light	3	3	3

The separation minima were also improved as a consequence of RECAT. These separation minima are expressed in nautical miles.

Table 5. Distance-based separation minima in nautical miles

Lead \ Follow	A	B	C	D	E	F
A	3	4	5	5	6	8
B	2.5	3	4	4	5	7
C	2.5	2.5	3	3	4	6
D	2.5	2.5	2.5	2.5	2.5	5
E	2.5	2.5	2.5	2.5	2.5	4
F	2.5	2.5	2.5	2.5	2.5	3

2.3 Scheduled Flights

2.3.1 Delay

As observed during actual time studies in the Manila Control Tower, the lack of instruments, especially the visual radar, is major disadvantage. Air traffic controllers rely solely on the radioed messages from the pilots. The aerodrome control unit and the approach control unit are not located in the same area in the tower; thus, the queue of arriving aircrafts is handled separately from that of the departing aircrafts. Communications between the two units would likely take less time if they were in a common room. The sequencing of aircrafts was seen to be on a first come, first served basis. Hence, aircrafts were not systematically arranged to observe minimum ROT. There were instances when the required minimum separation could have been reduced following a strategic queue. Lastly, international arrivals are allowed only on Runway 06/24, so flights must be planned to maximize arrivals because as an aviation rule, arrivals are given priority over departures.

To compute the delay, a queuing diagram was used and the plots in the diagram are tabulated in Table 6. The difference between the values in the capacity and the scheduled columns is the number of delayed aircrafts. The total queued aircrafts for Saturday is greatest equaling to 42 operations per hour, which basically means that during peak hours, all flights are expected to be delayed. The average delay experienced by each aircraft due to operational inefficiencies is at around 14 minutes.

Table 6. Delay Experienced per Aircraft

PERIOD	TOTAL DELAY EXPERIENCED	UNITS
FRIDAY PM	24	operations per hour
	10.5882	minutes per aircraft
SATURDAY AM	5	operations per hour
	6.1224	minutes per aircraft
SATURDAY PM	42	operations per hour
	14	minutes per aircraft

By solely following first-come-first-served as basis for the sequencing of flights, extended separation time between aircraft are prone due to a non-idealized sequencing as based on ICAO separation rules. As more aircrafts need to use the runway on a given time-frame, i.e. peak periods, a largely randomized mix of aircrafts get sequenced, which would then be highly probable to produce longer separation times, thus a longer runway occupancy time for each flights. For departing aircrafts, selection of runway is also a factor of possible delay. As only Runway 06/24 is capable of handling instrument flights, only this runway is used for arriving aircrafts. During peak periods, departing aircrafts on Runway 06/24 are subjected to a more limited time of operation on the runway, as successive arrivals are prioritized to use the runway, which furthers the delay experienced by departing flights.

2.3.2 Selection of Time Study Period

The cumulative number of flights operated only during peak hours was taken. The most number of regular scheduled flights occur on Fridays and Saturdays as shown in Table 7. This means that the top peak days are on Saturday and Friday. Actual observations for this research were conducted within 8:00-11:00AM and 2:00-6:00PM on Saturdays and Fridays of April.

Table 7. Cumulative Daily Flights During Peak Hours

Time \ Day	M	T	W	T	F	S	S
8:00:00	41	40	41	37	40	41	42
9:00:00	50	48	51	48	49	49	49
10:00:00	35	38	38	37	39	37	35
14:00:00	49	48	48	46	51	50	50
15:00:00	40	42	42	39	42	43	41
16:00:00	41	42	39	42	43	45	43
17:00:00	42	36	41	36	40	42	41
TOTAL	298	294	300	285	**304**	**307**	301

3. OBSERVED FLIGHTS

From the observed flights, the aircraft mix, reaction times, and rolling times were obtained. Also, it was the basis for the selection of sample data for simulation. The day with the highest corresponding cumulative flights was chosen. An example is shown in Table 8.

Table 8. Peak Operation for Saturday PM

Hour	16-Apr	23-Apr	30-Apr
1PM-2PM	44.43	43.09	41.58
2PM-3PM	45.27	41.87	37.43
3PM-4PM	41.20	44.73	40.11
4PM-5PM	44.64	24.07	47.92
5PM-6PM	36.14		42.17
SAT PM	**42.69**	42.53	42.39
	R=0.9989	R=0.9994	R=0.9978

4. ALGORITHMS

Two algorithms were produced for the optimization of flights - one for the scheduled flights and another for the observed flights. The processes for both the scheduled and the observed flights basically follow the flowchart. The algorithms were programmed in Microsoft Excel.

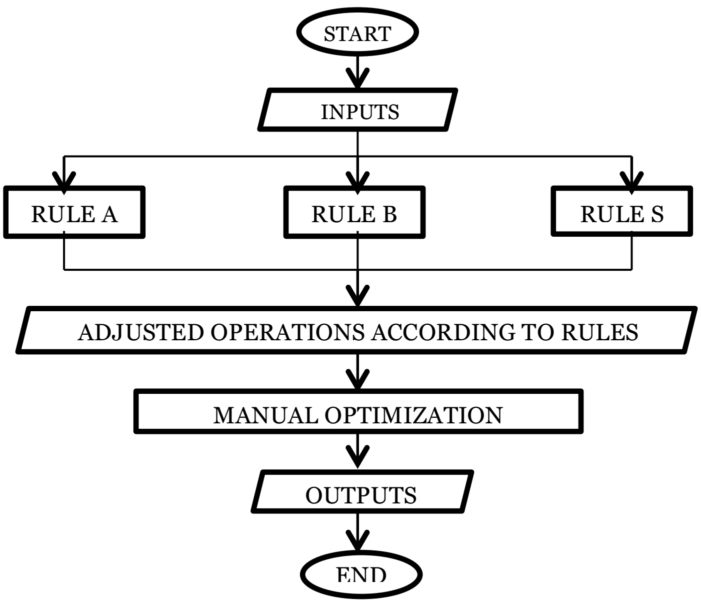

Figure 3. Optimization Flowchart

Prior to the program itself, both the scheduled and the observed flights were grouped into 15-minute blocks. Then, the input parameters of flights per 15-minute block were entered. These flights were automatically and simultaneously processed through three major rules, with their respective shortened labels below:

Separation Rules for Consecutive Departures: **Rule A**
Separation Rules for Following Arrival: **Rule B**
Sequential Operation Rule: **Rule S**

The application of these rules depends on the sequence of successive flights. Basically, these rules allow automated computation of runway occupancy times and overall duration of operations in a specific block. Details and specifications of these rules are further discussed in this section.

4.1 Algorithms for Scheduled Flights

4.1.1 Inputs

The parameters needed for the simulation of scheduled flights are listed and described below.

Table 9. Inputs for the Algorithm for Scheduled Flights

Input Parameter	Description
Flight Number (Flight No.)	Flight numbers are obtained from the schedule provided by MIAA.
Aircraft Type (Type)	This indicates the make and model of an aircraft, important in correctly categorizing them in two classification systems, namely RECAT and APC. RECAT specifies separation for consecutive departures on the same runway, while APC specifies the time-equivalent separation for consecutive approaches on the same runway.
Operation (D/A)	A departing aircraft is labeled "D"; an arriving aircraft is labeled "A".
Scheduled Time (SCHED)	Scheduled Time of Arrival (STA) is the time an arriving aircraft exits the runway through a taxiway. Scheduled Time of Departure (STD) is the time a departing aircraft passes the runway threshold (THR).
Runway (RWY)	All arriving aircrafts use Runway 06. For departing flights, a general rule is that all aircrafts under Aerodrome Classification codes A to C must use Runway 13/31 except for flights from Terminals 1, and 2. All code D and E aircrafts may depart only using Runway 06/24. Other airline- and aircraft-specific cases are observed.

The most critical factor for determining ROT is the sequence of two consecutive flights, or a sequential pair. The sequence indicates the runway and the operation of a preceding (P), and a following (F) aircraft. A sequential pair requires one of three main separation rules, which are labeled in this study as Rule A, Rule B, and Rule S. A new set of operational procedures was created for this simulation. It was patterned after the existing rules.

The flights are analyzed per 15-minute intervals. As per MIAA and CAAP protocols, an aircraft is delayed if it has not accomplished its operation within 15 minutes from its scheduled time of arrival or departure.

4.1.2 Process

Once the input values are placed, the algorithm will automatically produce an estimated Runway Occupancy Time (ROT), and Estimated Time of Arrival (ETA) or Departure (ETD), for each flight in the sequence.

<u>Sequencing</u>
The most critical parameter for determining ROT is the sequence of two consecutive flights. The sequence indicates the runway and operation of a preceding (P), and a following (F) aircraft. One of three main rules is assigned to each sequence. The rules are Rule A, Rule B, and Rule S.

Rule A

Rule A is applicable to consecutive departing flights of the same runway such as 06D-06D, and 13D-13D. The separation rule follows the time-based Wake Vortex Separation Minima (RECAT MIN) based on RECAT Aircraft Classification.

The Wake Vortex Separation Minimum is defined as the least allowable time difference between start of successive rolls for take-off. The separation minimum consequently starts once the preceding aircraft begins its roll. Once this minimum time difference has passed, and provided the preceding aircraft has completed its take-off roll and rotated, the following aircraft can then begin its roll for take-off. Thus, the effective Separation Time (SEP) is the difference between RECAT MIN and the preceding flight's roll for take-off. This Separation Time is assigned to the following aircraft.

The effective Rolling Time for Departure (RTD) of each aircraft is the sum of its Reaction Time (rT), and actual Take-off Roll (ROL). The section in the algorithm for Rule A is shown in the following table.

Rule B

Rule B is assigned to all sequences whose succeeding flight is in arrival.

Runway 06 requires a minimum of 5 NM of clearance between an arriving aircraft on approach and the runway. For a preceding arriving aircraft, i.e. 6A-6A, the lateral separation must always be maintained at 5NM such that when the preceding aircraft is over the landing threshold, the following aircraft is at the 5NM threshold. For flights departing prior an impending Runway 06 arrival, such as 6D-6A and 13D-6A, the preceding aircraft must have started its take-off roll as the arriving aircraft passes the 5NM threshold.

An arriving aircraft on Runway 13 must have a minimum of 3NM clearance between the aircraft and the runway. For consecutive arrivals, the succeeding aircraft must be laterally separated 3NM from the preceding aircraft. A prior departure for either runways must also start its take-off roll before the succeeding aircraft passes over the 3NM threshold. There are no scheduled Runway 13 flights so Rule B3 was not applicable.

Time-equivalent separation is used for each aircraft corresponding to the aircraft classification based Approach Speed Categories. The effective Separation Time (SEP) is the difference between the APC and the ROL of the preceding aircraft, which is then assigned to the following aircraft. The effective Rolling Time for Arrival (RTA) is also the landing roll for all aircrafts. The section in the algorithm for Rule B is shown in the following table.

Rule S

For all remaining sequences such as intersecting departures, i.e. 06D-13D and 13D-06D, and arrival prior a departure, i.e. 06A-06D and 06A-13D, there are no required minimum separations between the two sequences. As an example, a flight may immediately begin its takeoff roll on Runway 13 as the preceding flight departing on Runway 06 has reached the take-off threshold. Similarly, a departing aircraft on Runway 13 may begin its takeoff roll, once the preceding arriving aircraft has exited Runway 06. ATD for the following aircraft is the sum of its Reaction Time its actual rolling time. The section in the algorithm for Rule S is shown below.

After the application of Rules A, B, and S, the result is a block of flights with the same sequence as that of the scheduled, but with different ROT and total duration. As a quick check, the operation time of the last flight is compared to its original time. The preliminary result will usually show an earlier time. Furthermore, to produce a new flight schedule, the block of flights is manually optimized and reordered in order to maximize the effects of the Rules and the reductions in ROT that come with it. The result of further manual adjustment is a decreased ROT of 33 seconds.

4.1.3 Outputs

The output parameters of the algorithm are described and tabulated below. These are also used for the adjusted flight schedule.

Table 10. Output Parameters of the Algorithm for Scheduled Flights

Output Parameter	Description
Sequence Number (No.)	The numbering will follow the initial order of the input schedule.
Aircraft	The same details from the inputs will also be printed in the results.
Runway Occupancy Time (ROT)	The calculated Runway Occupancy Time for a flight is the sum of the assigned separation time (SEP), and its Rolling Time (RT_).
Estimated Time (ETD/ETA)	Time a flight leaves the runway, to be calculated using the algorithm.

By automatically providing ROT and ETD/ETA, it can easily be inferred how long a flight will complete its operation on the runway, which also reveals how long a particular sequence of flights will complete is duration. ROT is a direct indicator of capacity so manipulation of the sequence, which will automatically produce the corresponding calculated ROTs, would provide an easy way to optimize runway use.

4.2 Algorithms for Observed Flights

4.2.1 Inputs

The inputs for the algorithm for observed flights are quite similar to those of the scheduled flights. The main difference is that there are more time data points for observed flights.

Table 11. Inputs for the Algorithm for Observed Flights

Input Parameters	Description
Flight Number (Flight No.)	Each is mentioned during command exchange by the controller.
Aircraft Type (Type)	This indicates the make and model of an aircraft.
Time Data Points	
Entry	Time of actual entry or hover on runway entry threshold
Mid 1	For arrivals, this is the time of touchdown; for departures, this is the start of roll time
Mid 2	For arrivals, this is left blank; for departures, this is the time of wheels up
Exit	For arrivals, this is the time of full exit to a taxiway; for departures, this is the time of hover on runway exit threshold
Operation (D/A)	A departing aircraft is labeled “D”; an arriving aircraft is labeled “A”.
Runway (RWY)	The runway that is used by an aircraft during actual operations.
Sequence	The sequencing of air traffic controllers in Manila follows a first-come-first-served basis, regardless of aircraft category. This sequence is used to determine current maximum capacity.

4.2.2 Process

The observed flights are again clustered into 15-minute blocks using the same principle for delay. The algorithm for observed flights runs two simultaneous calculations that produces two different sets of Actual Flight Times (ATA/ATD). The first is through direct measurement of actual time data points, while the second calculation is the utilization of the adjusted sequencing through the application of RECAT Minima, and ICAO Approach Separation Minima. The flights are run through algorithms using Rule A, Rule B, and Rule S, as expounded in the previous section.

For departing flights, the Rolling Time for Departure (RTD) is the duration from the Entry into Runway (ENT) to the Take-off Threshold (THR). The Rolling Time for Arrival (RTA) is the duration from the Landing Threshold (THR) to the Exit to Taxiway (EXT). Separation Time (SEP) is the direct difference between the succeeding aircraft’s runway entry, ENT for departure and THR for arrival, and the preceding aircraft’s runway exit, THR for departure and EXT for arrival. SEP is applied to the following aircraft. Runway Occupancy Time is the sum of the Separation Time and Rolling Time.

The actual time of operation (ATA/ATD) of the first flight for each 15-minute block is considered the start of the sequence. Rolling Time (RTA/RTD) is still dependent on the actual observed rolling times of each flight. Separation rules, namely Rules A, B, and S, are also applicable to Adjusted Observed Sequence. The application of these rules will result to new Actual Time of Arrival/Departure

(ATA/ATD) for each aircraft. They are still considered Actual, instead of Estimated, because the rolling time, reaction time, and separation times are based on actual operations instead of theoretical values. The total duration of flights will also be changed as a result of the algorithm.

After the automatic calculation of new ATA/ATD based on the rules, the sequence of flights in the 15-minute block is altered. The total duration of operations is still reduced.

4.2.3 Outputs

The output parameters of the algorithm are described and tabulated below. These are also used for the adjusted flight schedule.

Table 12. Output Parameters of the Algorithm for Observed Flights

Input Parameters	Description
Sequence Number (No.)	The numbering will follow the initial order of the input schedule.
Aircraft	The same details from the inputs will also be printed in the results.
Runway Occupancy Time (ROT)	The calculated Runway Occupancy Time for a flight is the sum of the assigned separation time (SEP), and its Rolling Time (RT_).
Actual Time (ATD/ATA)	The time each flight leaves the runway, by hovering above the threshold for departures, or by exiting through a taxiway for arrivals, will be calculated using the algorithm for observed flights.

Similar to the Scheduled Flights Algorithm, ROT and ATD/ATA are automatically provided by the Observed Flights Algorithm. In adjusting the sequence to achieve highest capacity, the total Runway Occupancy Time for a sequence of flights will also automatically show in the results.

4.3 Specifications on Operational Rules

The air traffic controllers (ATC) from CAAP follow certain rules for actual operations. The operation rules specifically for runway configuration 06 and 13 are summarized in Table 9. These rules are mainly for the maintenance of separation minima, and for safety measures. Note that ICAO categorization of aircrafts is used by the ATC.

Table 13. Current Operational Rules

OPERATION		SEPARATION PROTOCOLS
Preceding	Following	
06D	06D	Time-based Separation
06D	13D	After passing runway intersection, following is clear to roll
06D	06A	After crossing threshold, following must be at 5nm threshold
06D	13A	After passing runway intersection, following must be at 3nm threshold
13D	06D	After passing runway intersection, following is clear to roll
13D	13D	Time-based Separation
13D	06A	After passing runway intersection, following must be at 5nm threshold
13D	13A	After crossing threshold, following must be at 3nm threshold
06A	06D	After exiting to taxiway, following is clear to roll
06A	13D	After exiting to taxiway, following is clear to roll
06A	06A	After crossing threshold, following must be at 7nm threshold
06A	13A	After crossing threshold, following must be at 3nm threshold
13A	06D	After exiting to taxiway, following is clear to roll
13A	13D	After exiting to taxiway, following is clear to roll
13A	06A	After crossing threshold, following must be at 3nm threshold
13A	13A	After crossing threshold, following must be at 7nm threshold

After the operation under the Preceding column, the succeeding operation under the corresponding Following column may only be allowed if the new separation protocols are satisfied. The short-hand label for the separation rule applicable to a sequential pair is noted under the Rule column. This was indicated for simplicity of the algorithms.

Table 14. New Operational Procedures

OPERATION		RULE	SEPARATION PROTOCOLS
Preceding	**Following**		
06D	06D	**A**	Time-based Separation
06D	13D	**S**	After passing runway threshold, following is clear to roll
06D	06A	**B**	After start of takeoff roll, following must be at 5nm threshold
06D	13A	**B**	After start of takeoff roll, following must be at 3nm threshold
13D	06D	**S**	After passing runway threshold, following is clear to roll
13D	13D	**A**	Time-based Separation
13D	06A	**B**	After start of takeoff roll, following must be at 5nm threshold
13D	13A	**B**	After start of takeoff roll, following must be at 3nm threshold
06A	06D	**S**	After exiting to taxiway, following is clear to roll
06A	13D	**S**	After exiting to taxiway, following is clear to roll
06A	06A	**B**	After passing landing threshold, following must be at 5nm threshold
06A	13A	**B**	After passing landing threshold, following must be at 3nm threshold
13A	06D	**S**	After exiting to taxiway, following is clear to roll
13A	13D	**S**	After exiting to taxiway, following is clear to roll
13A	06A	**B**	After passing landing threshold, following must be at 5nm threshold
13A	13A	**B**	After passing landing threshold, following must be at 3nm threshold

4.4 Manual Optimization

Changing the sequences of the flights was done manually because careful inspection and evaluation was needed. There are times when the sequencing is at the discretion of the researcher; however, most of the time, the process of optimization follow certain patterns, initial basic procedures, and some important conventions. The pointers for manually optimizing the flights are summarized as follows:

1. Cluster the schedule into 15-minute blocks. Input one block of 15-minute schedule of flights in the algorithm.
2. The Input must have complete information for all flights in all columns: Flight No. (Col. 2), Type (Col. 3), D/A (Col. 4), RWY (Col. 5), and Sched (Col 6). Column 7 will display a red mark if there are any incomplete values. Columns 8, 9, and 10, show the flight's corresponding RECAT Code, APC Code, and Rolling Time, respectively.
3. The Output columns will automatically fill each flight's corresponding ROT, ETA, and ETD. The sequence's DURATION, START, and END, will also automatically be displayed on top of the Output columns.
4. Arrange the arriving aircrafts first by sorting RT (Col. 10) in a decreasing order, then sorting APC (Col. 10) in an increasing order. Designate an order in Column 11 by prioritizing APC Code A with decreasing RT values, followed by APC Code B with decreasing RT values. Followed by APC Codes C and D, with decreasing RT values. Lastly, APC Code E follows, also in decreasing RT values.
5. Arrange the departing aircrafts next by sorting RECAT (Col. 10) in a decreasing order. Designate an order in Column 11 by ranking RECAT Codes F to A.
6. Check the optimization recommendations for more options on rearranging the sequence.
7. Sort Column 11 to rearrange the sequencing.
8. The output columns will automatically fill each flight's corresponding ROT, ETA, and ETD. The sequence's DURATION should be shortened when compared to the original sequencing, indicating that the sequence requires less time to complete than the original.
9. If the DURATION value exceeds 15:00, strategically transfer an applicable number of flights to the previous or subsequent 15-minute blocks. Repeat Steps 3 through 5 for the new sequence and also for the previous or subsequent blocks where the number of flights were added to. Verify that the transferred flights are within 15 minutes of their original schedule.
10. Repeat Steps 1 through 7 for all 15-minute blocks, then compile the new sequencing to complete the revised day schedule.
11. Capacity is determined as the maximum number of flights of the runway system during peak hours of 8-6PM. This is calculated by dividing the total duration of ROTs from 8AM to 6PM over the cumulative number of flights during the same period.

5. UPDATED CAPACITIES

The optimization of scheduled flights resulted to the updated capacity, which is the targeted number of flight slots available for airlines.

Table 15. Summary of Current and Optimized Capacities

	TOTAL DURATION	N	CAPACITY
CURRENT	09:04:35	406	44 operations/hr
OPTIMIZED	08:33:05	406	47 operations/hr
Reduced Time	00:31:30		
% Reduction	5.8%		

The optimization of observed flights resulted to the updated maximum capacity, which is the targeted throughput for air traffic controllers. As observed, during actual flights, controllers and pilots try to accomplish their tasks as fast as possible. This leads to certain reductions in the runway occupancy times, so the capacity is stretched to a maximum capacity based during actual operations.

Table 16. Summary of Current and Optimized Maximum Capacities

	TOTAL DURATION	N	CAPACITY
CURRENT	11:15:26	519	46 operations/hr
OPTIMIZED	10:04:24	519	52 operations/hr
Reduced Time	01:11:02		
% Reduction	10.5%		

6. OPTIMIZED FLIGHT SCHEDULE

The changes applied to the current flight schedule resulted to a new optimized flight schedule with higher capacity and also an improved and more efficient system for actual operations. The optimized flight schedule includes all of the flights from the original Summer Flight Schedule from the MIAA.

7. CONCLUSION

From time studies conducted at the Manila Control Tower, the runway occupancy times of aircrafts for both arrivals and departures were recorded and analyzed in order to calculate the capacity and maximum capacity of the NAIA runway. New operational procedures were recommended for efficient transition of sequential flights. These operational procedures were summarized into three major separation rules, namely Separation Rules for Consecutive Departures (Rule A), Separation Rules for Following Arrival (Rule B), and Sequential Operational Rule (Rule S).

The three aforementioned runway operation rules were incorporated into the algorithms created for the optimization of both the scheduled and the observed flights at NAIA. The primary result was a sequence of flights with optimized runway occupancy times, rolling times, and reaction times. The initial outcomes were further optimized by manually reordering the flights until a sequence with the least runway occupancy time was produced. Adjustments were made on a case-to-case basis, hence this part of the simulation was not automated and, instead, done carefully by an operator. As a guide, included in this study are some recommended procedures for the manual optimization of flights. The new sequence is the final optimized flight schedule or the optimized observed flights.

Each day was divided into 1-hour time blocks, and the number of flights scheduled per hour was tallied. Blocks with more than 40 flights indicated overcapacity, which consequently signify manifestation of operational delays. Queuing diagrams for each study period showed the operational delays experienced per aircraft. Meanwhile, blocks with less than 40 flights indicated undercapacity, which meant that there are instances when the runway is underutilized. The flight schedule must have exactly 40 operations per hour to affirm that the NAIA runway is operating efficiently.

The planned flights were run through the algorithm such that the delays were eliminated and each hour block was maximized. Following the same sequence of flights, the updated value of the capacity of the NAIA runway is 44 operations per hour, which is 4 operations greater than the current declared value by MIAA. In short, the declared value must be 44 operations per hour, not 40 operations per hour. Furthermore, the algorithm follows a strict implementation of current operational protocols. After applying the rules and going through manual methodical optimization of the scheduled flights, the new and optimized capacity of NAIA is reported to be at 47 operations per hour. This is the targeted throughput of the Summer Schedule published. After rearranging the flights to get a capacity of 47 operations per hour, the Summer Flight Schedule was generated.

Similarly, the updated current maximum capacity of NAIA was calculated to be 46 operations per hour. This indicates an increase of 2 operations per hour from the declared capacity. By running the observed flights through the algorithm and by manual optimization, the new and optimized maximum capacity of the NAIA runway is at 52 operations per hour. This should be the target throughout of air traffic controllers. Actual operations can be completed faster by reducing the average rolling times and reaction times for each aircraft.

Operation officers, air traffic controllers, and approach control personnel from MIAA and CAAP may use the algorithms and the manual optimization guides. Utilization of these tools will help increase and maximize the runway capacity of NAIA.

8. RECOMMENDATIONS

To eliminate the operational delays, it is recommended to follow the rules on optimization of runway operations noted in this study. Utmost cooperation is needed between the controllers and the pilots so that operations are done sequentially with very minimal stalling periods.

The Optimized Flight Schedule and the algorithms must be examined and tested in actual runway operations. This was not in the scope of the study due to official and government protocols.

Additionally, runway capacity should be analyzed when other runway configurations are used. This is to confirm the comparisons made for the different runway configurations. Most importantly, based on previous studies, the RECAT was proven to be beneficial in maximizing the runway throughput of airport; hence, it is highly recommended for MIAA and CAAP to conform to the said aircraft categorization. Also, algorithms using the ICAO aircraft categorization (Heavy, Medium, Light) can be devised in order to compare and confirm the increase in capacity using the RECAT.

As observed during time studies in the Manila Control Tower, operations are managed visually and are highly dependent on the radioed information and locations from the pilots. There is no radar or monitor available to accurately pinpoint the location and estimated time of arrival of aircrafts. Instead of relying only on the senses and through work experience, the devised algorithms and procedures for optimization are based on time, which can be directly monitored through the clocks and timers available in the tower.

This study was mainly applied to the constituents of the Aerodrome Control Division of the Manila Airport. It is highly suggested that the Approach Control Division use the new operational procedures as well. The advantages of the optimized sequence of flights cannot be fully maximized if the approach/arrival patterns do not comply with the generated rules and conditions of the algorithm.

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