MODELING RUNWAY CAPACITY USING MIXED INTEGER PROGRAMMING BASED ON FCFS AND AROT POLICIES

Oki Anita Candra Dewi*
Department of Logistics Engineering, Universitas Internasional Semen Indonesia, Veteran Road, Gresik, 61122, Indonesia, Email: oki.dewi@uisi.ac.id

Puji Andayani
Department of Informatics Engineering, Universitas Internasional Semen Indonesia, Veteran Road, Gresik, 61122, Indonesia, Email: puji.andayani@uisi.ac.id

Faisal Riza
Air Traffic Controller, Air Navigation, Juanda, 61253, Indonesia, Email: ryuganaya@gmail.com

ABSTRACT
Air transportation are often used between islands and countries which have economic advantages over other types of transportation. Technology in aircraft enables an increase in demand from year to year. demand density creates a queue of aircraft on the runway. Airport faced challenge within a key bottleneck in the air transport system and runway schedulling. This study focuses on modeling runways using mixed integer programming with empirical studies at Juanda International Airport, Surabaya. We use runway capacity management baesd on schedulling approach, runway configuration and aricraft separation standard. This study is to minimize aircraft waiting time on the runway before departure and landing in the air with considerable reduction in delays and minimize in fuel cost. We proposed heuristic sequential approach based on FCFS and AROT policies. By conducting research using these methods, it is expected to obtain optimal results to facilitate decision making in daily operations.

Keywords: Air Transportation, Runway Capacity, Mixed Integer Programming, Aircraft Waiting Time.

1. INTRODUCTION

Transportation is one of the basic things in life today. Humans in the world are very dependent on how they move both people and goods from one place to another (Business Dictionary, 2011). . Transportation is very important for a country. This is because economic growth is influenced by the ability of a country's transportation. Apart from supporting economic growth, transportation can also support aspects of Indonesian tourism.

In Indonesia, public transportation is one of the main focuses in government. Several types of public transportation were improved including air transportation. Air transport facilitates integration into the global economy and provides vital connectivity on a national, regional, and international scale (World Bank, 2017). The World Bank has funded air transportation projects for more than sixty years (World Bank, 2017) with efforts to help generate trade, promote tourism, and create job opportunities (World Bank, 2017). In addition, there are several reasons people decide to choose a transport plane, namely air transportation is the most time-saving transportation compared to other types of transportation. The advanced technology in the aircraft allows this transport ten times faster than other types of transportation. However, the disadvantage of this transportation is that it is highly dependent on weather conditions. According to Graham (2014) an airport is a place that provides all the necessary infrastructure to allow passengers and shipments to transfer from other modes of transportation to air transportation and allow airlines to take off and land. The airport is divided into 2 based on the use of the facilities: the air side and the land side. Each airport consists of a runway (runway), taxiways, aircraft parking space (apron), gates, passenger and freight terminals, and ground transportation exchanges. The movement of airport aircraft in each region differs from one place to another. The movement of aircraft movements is based on several factors, such as the movement of the runway aircraft, safety factors, and others. Aircraft movement is a measure of the maximum number of aircraft operations that can be accommodated at an airport or airport component in one hour (Federal Aviation Administration, 1995).

Several airports in Indonesia that have contributed greatly to the increase in the number of passengers in Indonesia include Soekarno Hatta Airport, Juanda Airport, Hasanudin Airport, Ngurah Rai Airport, and Kualanamu Airport. Soekarno Hatta Airport as the busiest airport in Indonesia can depart and land as many as 50 million passengers a year. Juanda as the second busiest airport in Indonesia also has an important role. Although the number of passengers at Juanda is almost half that of Soekarno Hatta airport in Jakarta, the flow at the airport is still quite high compared to other airports. Juanda Airport is one of the airports in Indonesia which has a high target. According to the head manager, Juanda Airport has 28 capacities for normal flights and 5 capacities for emergencies. Juanda Airport can handle an average of 400 flights per day which includes flight arrivals and flight departures. However, sometimes there are delays that cause the flight flow not to function as scheduled.

One of the problems that occur at the airport is the runway sequencing problem (RSP).

Several studies discussing the RSP (runway sequencing problem) on a single runway are Julien et al (2017), Cetek (2014), Chao et al (2008), Irene et al (2007). According to Julien (2017) RSP consists of a sequence of runway operations that decide in which order and when each aircraft takes off, lands or crosses the runway by ensuring the level of safety in each sequence. In addition, Atkin et al (2007), Guepet (2016), Bennell et al (2011) and Lieder et al (2015) have also discussed ground routing problem (GRP) and runway sequencing problem (RSP). Deau et al (2008, 2009) discussed research on the sequential runway with the A-CDM approach. This study resolves the problem of the take-off sequence by targeting the take-off times (TTOTs) in the route model. Whereas Keith and Richard (2008) use mix integer programming (MIP) to integrate runway and ground routing in one model. According to Julien (2017) RSP consists of a sequence of runway operations that decide in which order and when each aircraft takes off, lands or crosses the runway by ensuring the level of safety in each sequence.

Therefore, this study will develop a model in calculating aircraft movements at airports using mixed integer programming with empirical studies at Juanda International Airport, Surabaya.

The paper is structured as follows in section 2 we state mathematical model formulation

Use indented instead of entered style for a new paragraph. When citing references, using the names of the authors and the year of publication is preferable. Here is an example. Smith (2005) suggested that the referencing style is one of the writing aspects that most students ignore when preparing a paper. Correspondingly, the references should be listed based on alphabetical order of the first author's last name.

2. MATEMATICAL MODEL FORMULATION

2.1 Formulation of Runway Capacity

The calculation of delay for a runway that is used exclusively by arrival is calculated from this equation (adopted from Bazargan, 2010)

$$W_a = \frac{\lambda_a(\sigma_a^2 + 1/\mu_a^2)}{2(1 - \lambda_a/\mu_a)}$$

Where,
Wa = Mean delay for aircraft arrival
ƛa = Mean arrival rate of the aircraft
µa = Mean service level of aircraft arrival or inverse mean service time
σa = Standard deviation of the mean service arrival time of the aircraft.

The calculation of delay for the runway used for departure (Departure) is calculated from the equation:

$$W_d = \frac{\lambda_d(\sigma_d^2 + 1/\mu_d^2)}{2(1 - \lambda_d/\mu_d)}$$

Where,
Wd = Mean delay for airplane departure
ƛd = Mean level of departure from the aircraft
µd = Mean service level for departure, or inverse average service time for departure
σa = Standard deviation of the mean service time from flight departures

For Mixed Operations, arriving aircraft are usually given priority and this aircraft delay is given by the arrival equation, but the average delay for departure in this situation can be found from the equation:

$$W_d = \frac{\lambda_d(\sigma_j^2 + j^2)}{2(1 - \lambda_d^j)} + \frac{g(\sigma_f^2 + f^2)}{2(1 - \lambda_a^f)}$$

Where,
Wd = Mean delay for airplane departure
ƛa = Mean arrival rate of the aircraft
ƛd = Mean level of departure from the aircraft
j = Mean interval of time between two successful departures
σj = Standard deviation of the mean time intervals between successful departures
g = Average rate of gaps between successful arrivals
f = Mean value of the time interval with no take-off departures
σf = Standard deviation from the time interval at which no departure has to be taken off

2.1 Heuristics Model

The heuristic approach in this study refers to Ghoniem (2014) who uses mixed integer programming (MIP), this model simultaneously searches for aircraft that enter the optimal aircraft runway by considering the separation policy between aircraft and the combination of arrival and departure. Ghoniem (2014) uses two runways in parallel and independently in carrying out the model while in this study the focus is on a single runway. Therefore, this research model refers to Ghoniem's (2014) runway capacity management (RCM) research which is formulated as follows:

$$minimize \sum_{j \in J} W_j(t_j - r_j)$$

With the attribute as follow:

$$\sum_{i \in N} Z_{ij} = 1, \quad \forall j \in J$$

$$r_j \leq t_j \leq d_j, \quad \forall j \in J$$

$$t_{j2} \geq t_{j1} + P_{j1j2} - M(1 - y_{j1j2}), \forall j_1 \in J, j_2 \in J, j_1 \neq j_2$$

$$y_{j1j2} + y_{j2j1} \geq Z_{ij1} + Z_{ij2} - 1, \forall i \in N, j_1 \in J, j_2 \in J, j_1 \neq j_2$$

$$y, z \; binary$$

Where,

C_j is the fuel consumption required by the aircraft according to the type and type of operation

j∈J is each aircraft up to the number of J which carries several characteristics (i) the type of operation (i.e. departure or arrival) (ii) the type of aircraft weight (small, large, heavy) (iii) the ready time and duedate schedule of the aircraft is known (iv) the aircraft's fuel needs

r_j is the ready time / flight schedule at juanda airport

t_j is the time when the plane to j will be assigned to the runway

d_j is the duedate aircraft accessing the runway

P_{j1j2} is the minimum required separation time between consecutive assigned aircraft. This separation time uses the minimum flight rules set by ICAO

M is a scalar number (large number) to help the program if airplane pairing is not selected. In finding M using $M = d_{j1} - r_{j2} + P_{j1j2}$

Z_{ij} has a binary value which means the number of runways used

y_{j1j2} has a binary value which shows the order of selecting the aircraft assigned to the runway, this shows the relationship between employee j1 and plane j2 if selected then it is 1 if not selected then it is zero (0)

3. RESULT

This model minimizes the total cost of fuel that is obtained from the difference between the ready time and the time assigned to the runway. The fuel costs are assumed to be in the index as in table 1 below. The table shows that the fuel consumption required between departure (D) aircraft types is different from arrival (A) aircraft, which means that arrival requires a higher fuel consumption than departure so that the arrival of MIP can be selected first if there is an incident of two planes at the same time. at the same time there is departure and arrival. Likewise for small, large and heavy aircraft types, the model will choose the minimum result by not exceeding the duedate of each aircraft type. In determining the cost of fuel by type and type, researchers used a visual basic application (VBA) in Microsoft Excel.

Table 1. cost index and type of aircraft

index cost	
S	1
L	1,5
H	1,75

tipe of aircraft	
D	1
A	1,5

This model also considers the separation time or standard time between aircraft as defined by ICAO. If there is a Departure-Arrival aircraft, the minimum required separation time is 35 seconds. Meanwhile, for Arrival-Departure aircraft, it takes a minimum of 120 seconds between aircraft to be assigned to the runway. For the Departure-Departure type of operation, pay attention to the type of aircraft which can be seen in table 2 below. If the Arrival-Arrival type of operation can be seen in table 5.3. When assigning the aircraft, it is necessary to pay attention to the type of heavy or small or large aircraft that will be compared with the next aircraft, it must meet the predetermined minimum standards.

Table 2. Separation time minimum for departure-departure (second)

Lead Aircraft Type	VFR* Trail Aircraft Type			IFR Trail Aircraft Type		
	Heavy	Large	Small	Heavy	Large	Small
Heavy	90	120	120	120	120	120
Large	60	60	50	60	60	60
Small	50	45	35	60	60	60

*These are shown to appropriately represent these operations and are not regulatory in nature.

Source: Federal Aviation Administration

Table 3. Separation time for arrival-arrival (nm)

Lead Aircraft Type	VFR* Trail Aircraft Type			IFR (Wake Vortex) Trail Aircraft Type		
	Heavy	Large	Small	Heavy	Large	Small
Heavy	2.7	3.6	4.5	4.0	5.0	6.0
Large	1.9	1.9	2.7	3.0	3.0	4.0
Small	1.9	1.9	1.9	3.0	3.0	3.0

*These are shown to appropriately represent these operations and are not regulatory in nature.

Source: Federal Aviation Administration

The separation time in this model is formulated with P_{j1j2} which accommodates the four flight rules. This study calculates separation time using a visual basic application (VBA) in Microsoft Excel with the formulations shown in the appendix. The model display in Excel can be seen in the following figure:

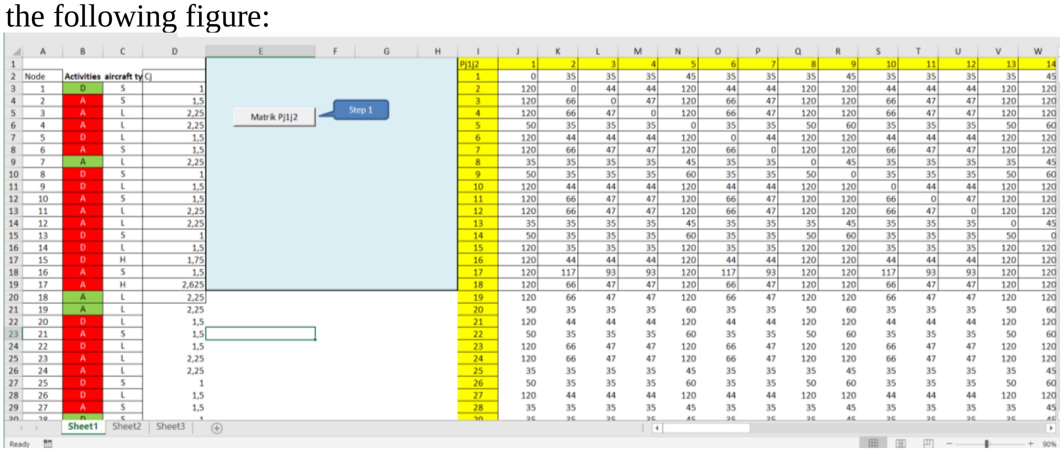
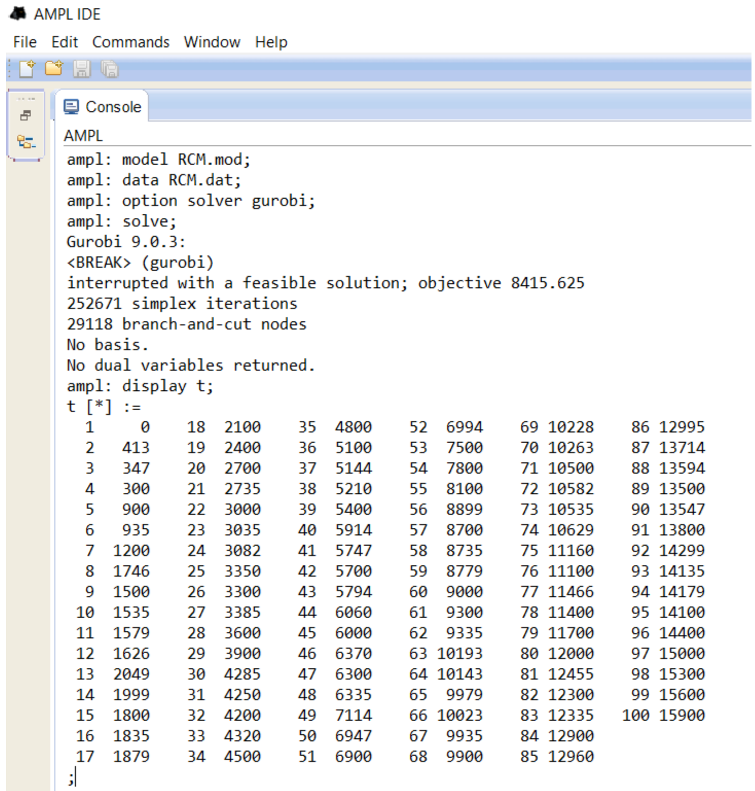


Figure 1. Matrix Calculation of P_{j1j2}

The results of running AMPL software can be seen in Figure 2. This model is running using Gurobi 9.0.3 solver and produces a feasible solution.



```
AMPL IDE
File  Edit  Commands  Window  Help
Console
AMPL
ampl: model RCM.mod;
ampl: data RCM.dat;
ampl: option solver gurobi;
ampl: solve;
Gurobi 9.0.3:
<BREAK> (gurobi)
interrupted with a feasible solution; objective 8415.625
252671 simplex iterations
29118 branch-and-cut nodes
No basis.
No dual variables returned.
ampl: display t;
t [*] :=
  1      0    18  2100    35  4800    52  6994    69 10228    86 12995
  2    413    19  2400    36  5100    53  7500    70 10263    87 13714
  3    347    20  2700    37  5144    54  7800    71 10500    88 13594
  4    300    21  2735    38  5210    55  8100    72 10582    89 13500
  5    900    22  3000    39  5400    56  8899    73 10535    90 13547
  6    935    23  3035    40  5914    57  8700    74 10629    91 13800
  7   1200    24  3082    41  5747    58  8735    75 11160    92 14299
  8   1746    25  3350    42  5700    59  8779    76 11100    93 14135
  9   1500    26  3300    43  5794    60  9000    77 11466    94 14179
 10   1535    27  3385    44  6060    61  9300    78 11400    95 14100
 11   1579    28  3600    45  6000    62  9335    79 11700    96 14400
 12   1626    29  3900    46  6370    63 10193    80 12000    97 15000
 13   2049    30  4285    47  6300    64 10143    81 12455    98 15300
 14   1999    31  4250    48  6335    65  9979    82 12300    99 15600
 15   1800    32  4200    49  7114    66 10023    83 12335   100 15900
 16   1835    33  4320    50  6947    67  9935    84 12900
 17   1879    34  4500    51  6900    68  9900    85 12960
;
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Figure 2. AMPL Running Result

Running with alternative 1 cost of using fuel by taking into account the difference between arrival and departure and aircraft type can be seen in Figure 3 below. Whereas alternative 2 scheduling does not pay attention to the fuel cost of each type but rather prioritizes the type and type of aircraft.

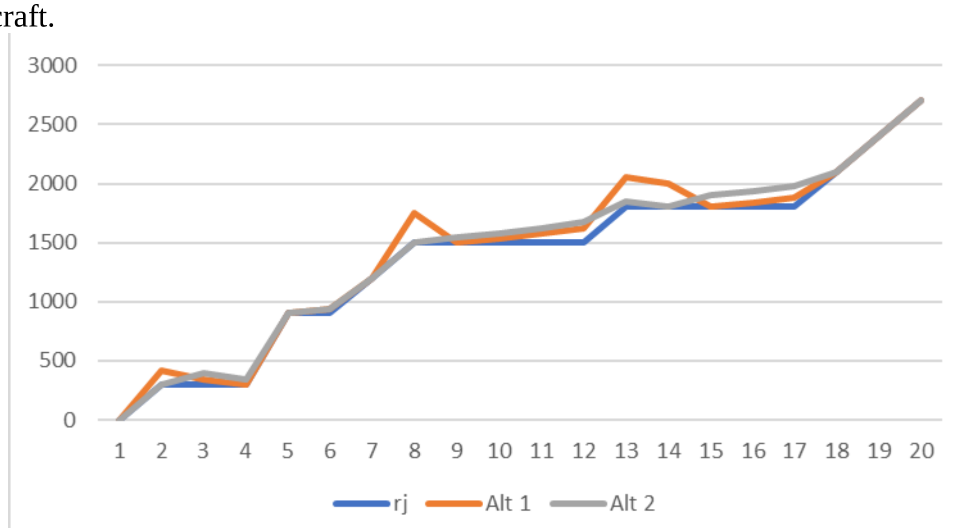

Figure 3. Alternative 20 flight schedule chart

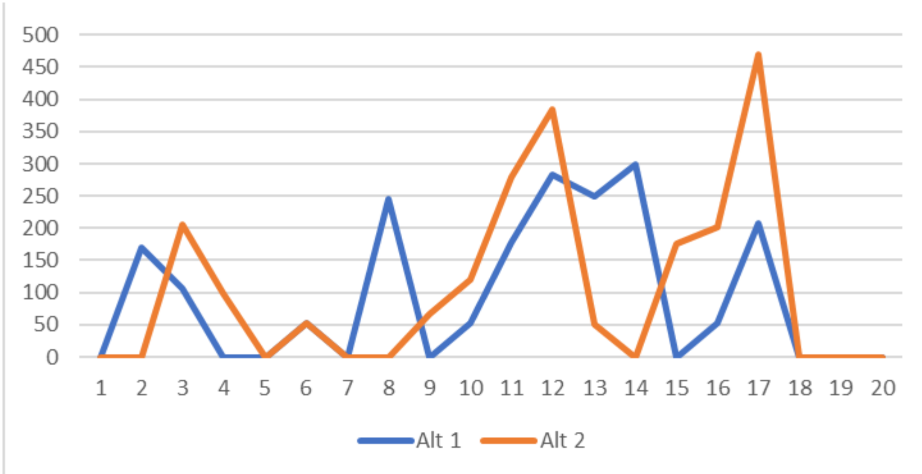

Figure 4. Graph of fuel usage consumption

Meanwhile, the results of the cost fuel generated from the 2 alternatives show that alternative 1 has lower fuel consumption compared to alternative 2.From these results, MIP can be applied in scheduling aircraft departing and arriving at the same time so as to reduce the cost of using fuel while waiting. assigned to the runway.

4. CONCLUSION

This research can produce a schedule that can save the cost of using fuel on each aircraft while on the runway using mixed integer programming. By using 2 alternatives it can be compared that alternative 1 is more minimum than alternative 2. Alternative 1 considers the fuel cost of each type and type of aircraft and prioritizes arrival, while alternative 2 only considers the type and type of aircraft and is close to ready time. From these results, MIP can be applied in scheduling aircraft that depart and arrive at the same time so as to reduce the cost of using fuel while waiting to be assigned to the runway.

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