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Designing Gate Assignment Model to Find the Optimum Airport Gate Assignment Order

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Abstract: The growth of aviation industry in Indonesia accelerates the escalation of Airport Gate Assignment Problem in the Soekarno Hatta International Airport. The gate assignment issue mainly influence passenger satisfaction over the general flight service. This research was conducted to develop Gate Assignment Optimization in the Soekarno Hatta International Airport, focused on minimizing the number of Un-gated Flights. This paper propose a meta-heuristic approximation approach namely simulated annealing to solve the Gate Assignment Problem. Output of this paper is the aircraft Gate Assignment Order at Terminal 2 Soekarno Hatta International Airport. The result suggests, decreasing number of Un-gated Flights occurred with the implementation of the proposed method. This research may be developed in the future by adding another objective function such as minimizing passenger walking distance and constructing real time based model.

Keywords: Gate assignment problem, optimization, stochastic, simulated annealing, un-gated flights, real time.

Introduction

Indonesia is one of the largest archipelagic countries in the world, she has 17,504 islands scattered throughout region. The number shows that Indonesia needs a reliable transportation system to accommodate people mobilization. Based on the span and necessity to cut travelling time, air transportation would be deemed as the best option for addressing the Indonesia's growing needs of inter-island transportation. Aviation sector has become one of the main transportation sectors in Indonesia. Furthermore, the number of passengers and cargo in Indonesia continuously increased from 2009 until 2013 (see Table 1). It is also expected an increase to 5%-10%, moreover by presence of ASEAN Open Sky on 2015 (FME-CWM[1]).

According to Airport Traffic Statistics[2], Soekarno Hatta International Airport (SHIA) as one of the main gate of Indonesia, becoming the 9th busiest airport in the world. On 2012, SHIA accommodated more than 57 million passengers and based on a research done by FME-CWM[1], it is estimated that more than 87 million passengers will be accommodated on 2025.

There are also more airports in Indonesia to operate above their capacities. Approximately 600 airports around Indonesia are now operating more than their capacities.

Table 1. Airline Passenger and Cargo Growth (2009-2013)

Year	Domestic Departure		International Departure	
	Passenger (x 1000)	Cargo (Ton)	Passenger (x 1000)	Cargo (Ton)
2009	41,691	288,651	8,016	157,904
2010	48,872	375,760	9,466	178,895
2011	59,276	463,507	10,745	178,797
2012	70,682	520,561	11,749	195,181
2013	73,595	525,412	13,221	210,733

Source: Biro Pusat Statistik [2]

Furthermore, SHIA has been operated more than 2 times of its capacity. It causes the lack performance of operational system. One of the operational systems which has been affected is Gate Assignment Problem (GAP). GAP mainly focuses on assigning a given set of arriving flights to a given set of gates available (Seker and Noyan [3]). According to Airport Operation Center [2] data, that more than 30% flights are classified as un-gated flights. Un-gated flight is a condition when an aircraft is not parked in a gate. In this research, gate refers to aircraft parking stand with aerobridge on its side. Those un-gated flights will affect the passenger satisfaction which then affect to the airport image.

Methods

According to its function, gate is a place where the aircraft being parked and a place where the passengers can board into the aircraft. Generally, each gate is always provided with an aerobridge which use as bridge between boarding lounge and aircraft.

GAP is a common problem happens in airports all over the world. Most literatures about GAP are

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focused on passenger travelling distance regarding to passenger satisfaction. The GAP tries to find an optimal or near-optimal assignment with respect to a specific objective function while satisfying the strict and some soft constraints, such as minimizing the number of un-gated flights and minimizing the towing activities in apron (Seker and Noyan[3]). There was a research done by Genc *et al.* [4] with case study in Istanbul Ataturk Airport, which was focused on maximizing the total duration of the flights assigned to the gates. Another issue was done by Maharjan and Matis [5]. They developed a multi-commodity flow network model at the George W. Bush Houston Intercontinental Airport (IAH), which focused on balancing the carrier efficiency and passenger comfort, while providing buffers for unexpected events that cause assignment disruptions. Different to other researches which are only focusing on static gate assignments, Yan *et al.* [6] discussed about a simulation framework which is not only able to analyze the effects of stochastic flight delays on static gate assignments, but can also evaluate flexible buffer times and real time gate assignment rules. Generally, most researches about GAP are based on the perspective of airport authority. Tan and Wang [7] have already done a research about GAP based on the airline's perspective rather than airport authority, with a focus on assigning certain flights to certain gates based on the airline's preference.

One of methods which usually used in GAP is Simulated Annealing (SA). SA is classified as a metaheuristics method, which most researchers use to find the most optimal solution in a short time (Setiawan and Palit [8]). There is an application of SA in GAP which is done by Drexl and Nikulin [9]. They collaborated SA with Pareto Methods in a multiple objectives model, namely to maximize total flight gate preference, to minimize the number of towing activities, and to minimize the absolute deviation of the new gate assignment from a so-called reference schedule. SA is mostly used in stochastic based problem which attempt to model uncertainty in the data by assuming that part of the input is specified in terms of a probability distribution (Shmoys and Swamy [10]). SA was developed by various researchers in 1980s. This algorithm was being adopted from the Metropolis Algorithm, which was developed by Nicholas Metropolis, Arianna and Marshall Rosenbluth, Augusta and Edward Teller in 1953 (Luke [11]). SA is an analogy of a process of cooling molten metal. The process of cooling is done by decreasing the temperature slowly. The speciality of SA algorithm is on its acceptance criteria. In SA, when the new solution is worse than the old, the new one will not automatically rejected. They still can replace the old solution with a certain probability.

There are 4 main parameters of SA that are used as indicators of the iteration performed in a model simulation. These parameters are: (1) Temperature which expresses the initial temperature used in the beginning of solution search. (2) Final Temperature which expresses the final temperature which also used as stopping criteria of a simulation. (3) Cooling Rate which expresses the speed of temperature drops. This parameters value is between 0-1. (4) Acceptance Probability which expresses the acceptance criteria of worse solution.

Those parameters will determine the number of iterations, which is the larger number of iterations the better solution can be obtained by the algorithm (Ai and Mahulae[12]).

This research focus on constructing a Gate Assignment Model, with case study in Terminal 2 SHIA. This paper propose a meta-heuristics approximation approach to give better result on GAP namely using simulated annealing algorithm. Simulated annealing was selected due to its ability to generate a one single solution rather than in a group of population, therefore it would not need any computer memory which then the iterations could be done faster. The objective function of this model is to minimize the number of un-gated flights which then will generate the optimum Gate Assignment Order. This model could accommodate the gate assignment based on the route type for each flight, such as international and domestic.

Model Construction

First step of model construction is gathering and collecting data. The data are mentioned below: Flight Schedule Data, used as the input of the model.

Operational Historical Data, used to find the gap between scheduled data and factual data. This data then being distributed as the random data (stochastic) to accommodate the real condition of the flights schedule, for example delay of some flights. The random data will be only used on arrival time variable and departure time variable.

Terminal Layout, used as the basis while identifying the number and route type allocation of gates. Factually, there are 3 sub terminals in terminal 2 SHIA, which are terminal 2D, 2E, and 2F. All international flights are allocated to sub terminal 2D and 2E, but domestic flights are allocated to sub terminal 2F. There are total of 24 gates in terminal 2 SHIA, which are each sub terminals are provided with 8 gates.
Based on the data gathered, then the model was defined by the objective function and the constraints

of the optimization model. The mathematical models are (Drexl and Nikulin [9]):

Objective function is minimizing the number of un-gated flights:

$$Min\ Z = \sum_{i=1}^{n} \pi_{i,m+1} \quad (1)$$

constraint to
Every aircraft is assigned to one gate only.

$$\sum_{k=1}^{m+1} \pi_{i,k} = 1, 1 \le i \le n \quad (2)$$

List of international flights will be ordered prior to list of domestic flights.

$$P + Q = N, 1 < i < p = P, p + 1 < i < n = Q \quad (3)$$

International flight will be only assigned to gate 1-16. This formula basically describes about all international flight will be only assigned to gate in sub terminal 2D and 2E.

$$\sum_{k=1}^{16} \pi_{i,k} = 1, 1 \le i \le p \quad (4)$$

Domestic flight will be only assigned to gate 17-24. This formula basically describes about all domestic flight will be only assigned to gate in sub terminal 2F.

$$\sum_{k=17}^{24} \pi_{i,k} = 1, 1 \le i \le q \quad (5)$$

There are no overlapping between two flights assigned to the same gate.

$$\pi_{i,k}\pi_{j,k}(d_j - a_i)(d_i - a_j) \le 0,$$
$$1 \le i, j \le n, k \ne m + 1 \quad (6)$$

Variables to be Boolean.

$$\pi_{i,k} \in \{0,1\}, 1 \le i \le n, 1 \le k \le m + 1 \quad (7)$$

Notations
n : number of flights
N : list of flights
p : number of international flights
P : list of international flights
q : number of domestic flights
Q : list of domestic flights
m : number of gates
a_i : arrival time of flight i
d_i : departure time of flight $i, (a_i < d_i)$
$\pi_{i,k}$: flight i is assigned to gate k

The next step is constructing the algorithm. Algorithm is a set of commands used to solve problem.

The complete of algorithm of the model in this research is provided in Appendix. Basically, the algorithm is divided into 8 sections, such as: (1) Getting the data. (2) Defining the SA parameters. (3) Defining the initial solution. (4) Defining the flight types which are international flights or domestic flights. (5) Commanding to assign each aircraft to available gates or remote area. (6) Defining the requirement to decrease the temperature. (7) Defining the acceptance criteria when the new solution is worse than the old solution. (8) Defining the requirement to select the best solution.

Figure 1 and Figure 2 shows the model results. Figure 1 show gantt chart which visualize Gate Assignment Order each day. It shows each gate assigned to flights in 24 hours time period. The purpose of this chart is to show gate availability and gate utilization. While, Figure 2 shows the comparison between the numbers of gated flights and un-gated flights on a day. The figure shows that the most crowded time happens on 15 PM – 22 PM.

Results and Discussions

The model was being verified by comparing the algorithm to the source code, to show that the model is appropriate to the model conceptualization. Then, the model was also being validated by comparing the model configuration to the factual data. The configurations which are compared are flight data used and the gates allocation. The model was iterated based on of the 27 combinations. Those combinations were formed based on 3 configuration values in each SA parameters. Each value in each parameter was selected based on their different level in each parameter and the iteration numbers want to be done. Every combination will be assessed by the solution generated and the iteration time. Values set to the temperatures are 1000000^o, 100000^o, and 10000^o; final temperatures are 100^o, 10^o, and 1^o; and cooling rates are 0.7, 0.3, and 0.1. The model was iterated using the data range from April 13 to 19, 2014.

Figure 3 shows that the model is able to provide improvement in the GAP system in Terminal 2 SHIA. The improvement is the decreasing number of un-gated flights based on model result compared to the number of un-gated flights based on the factual data obtained. This was caused by algorithm used in the model is generate the best solution from all iterations, not only based on the initial solution that is not necessarily the best solution. The graph also shows the high gap between the model result and factual data which showed on date April 15th, April 17th, and April 19th. This condition was caused by the existence of extreme disruptions. Those extreme disruptions could appeared in the form of bad weather which caused many delayed flights. Those delayed flights would caused the domino effect to the next flights and would interrupt the gate schedule that has already been generated.

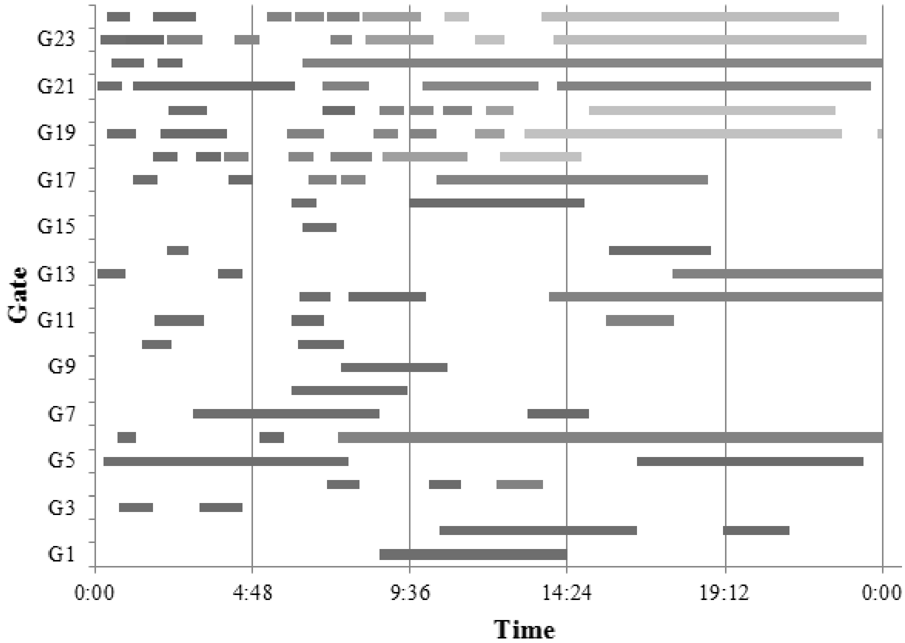

Figure 1. Gate Assignment Order

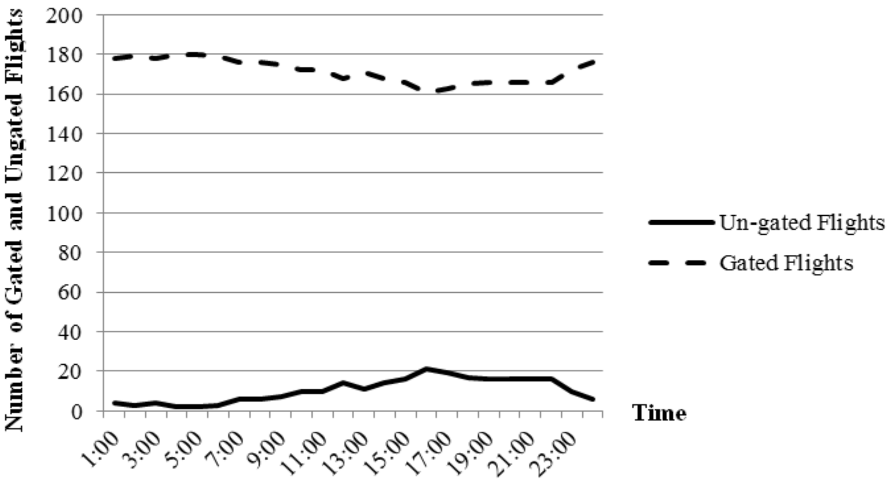

Figure 2. Comparison Graph between Number of Gated Flights and Un-gated Flights

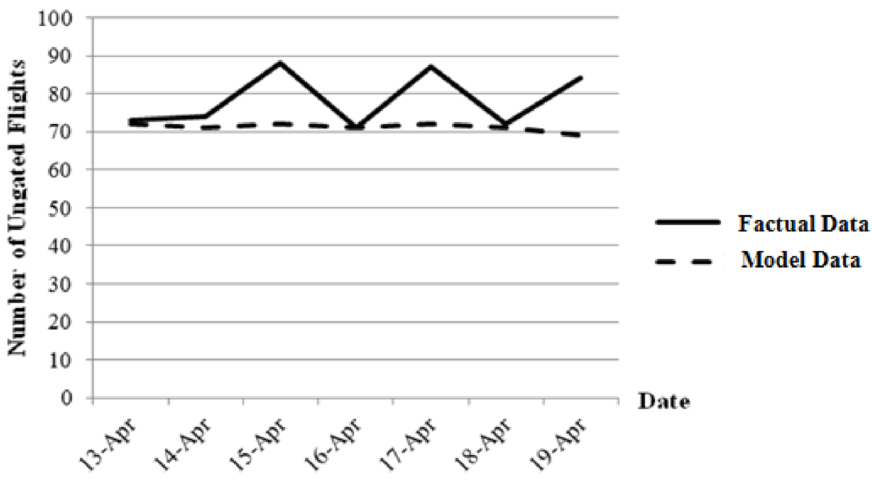

Figure 3. Comparison Graph of the Number of Un-gated Flights in Factual Data and Simulation Results

Conclusion

Based on the model constructed using simulated annealing algorithm is able to provide improvement in the GAP system in Terminal 2 of SHIA. The improvement is the decreasing number of un-gated flights compared to the number on factual data which indicate that the system is run more optimally.

In the lights of the model result, future researches are required to develop model with additional optimization objective function such as minimizing passenger walking distance. The research is also possible to be developed by integrating the runway allocation, with another objective function such as minimizing the number of delay flights. The previous part has already discuss about the extreme disruptions. Those disruptions are usually happens unexpectedly. Therefore, the development of real time based model rather than static based model will be very important to be considered.

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Appendix

Model Algorithm

```
GET Input Data
SET Temperature
SET Cooling Rate
SET Final Temperature
SET Best = -1
WHILE Temperature  > Final Temperature
    SET Arrival Time, Departure Time = Random
    SET S, R = -1
    SET R = 0
    FOR 1 to Input Data.Count
        IF Route Type = "International" THEN
            IF International Gate == exist THEN
                Assign Flight to International Gate
            ELSE
                Assign Flight to Apron
                R++
            ENDIF
        ELSEIF Route Type = "Domestic" THEN
            IF Domestic Gate == exist THEN
                Assign Flight to Domestic Gate
            ELSE
                Assign Flight to Apron
                R++
            ENDIF
        ENDIF
        IF (R < S AND S <> -1) OR S = -1 THEN
            S = R
            Temperature = Temperature – Cooling Rate * Temperature
        ELSEIF R > S THEN
            IF (random number chosen from 0 to 1) < e^((R-S)/Temperature) THEN
                S = R
                Temperature = Temperature – Cooling Rate * Temperature
            ENDIF
        ENDIF
        IF (S < Best AND Best <> -1) OR Best = -1 THEN
            Best = S
        ENDIF
    ENDFOR
ENDWHILE
PRINT Output
```