Review Study on Runway Capacity Parameters and Improvement

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Review Study on Runway Capacity Parameters and Improvement

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Abstract. The demand of air travel continues to increase over time, due to its short travel time, reliability and safety. Problems then arise when airport capacity, especially airside (mainly runway) capacity cannot cope with the demand. Some airports build the expensive additional infrastructure, while some others believe that manage on system is more efficient and effective. The study gathering information from various source about parameters related to runway capacity so that the improvement made in the future will solve right on target. To accommodate wide number of factors, the study classify the parameters into five categories in which operation/procedure related parameters play an important role (52%). To facilitate future research on runway capacity, the study also tabulates methods used by various scholars to improve runway capacity.

1. Introduction

Domestic air travel growth in Indonesia is dealing with 16.25% increase in passenger’s number from previous year [1] in which Juanda International Airport in Surabaya (SUB) contributes 9.78% from total national passenger. As one of the biggest airport in Indonesia, Juanda faces the classic capacity problem, they have to continue accommodate demand rate of runway use (both for departure and arrival) which is increasing over time.

Furthermore, Angkasa Pura I as the airport management operator that responsible to manage Juanda states that the airport need for urgent actions to address its overcapacity with their significant growth in passenger number (13% per year). According to that, the existing and planning actions to increase Juanda’s capacity are operate an additional terminal (Terminal 2), preparing masterplan for another additional terminal (Terminal 3) and two other runways. The solutions mentioned before require additional infrastructures build and hence generate huge additional cost and land acquisition problems.

However, with a closer look to the actual data shows in Figure 1, Juanda capacity problems didn’t appear in the whole slot time. The runway fails to serve demanded movements typically happen only in morning peak hours, and the rest movements satisfied by the existing runway. The current management system and coordination between infrastructures, technology and the stakeholder seems not working properly, and the easiest way come in first is to expand physical area as mentioned before.

In contrary to the solving actions done by Juanda, several researches from scholars, institutions, government agencies studied the more efficient and effective way to optimize runway capacity and minimizing the desire to build another costly infrastructure.

According to Abeyratne [3], Secretariat Study Group on Traffic Peaks at International Airports proposed a couple of solution in order to manage airport congestion more efficiently, which were
looking for any possible solution to satisfy the peak time and improve the traffic flow management quality.

![Figure 1. Daily Movement vs Declared Capacity on Juanda Airport](image)

The other approach are: solving aircraft landing and takeoff problems and simulate model that satisfy different stakeholder simultaneously [4], and study on wake turbulence on each aircraft type and sequencing aircraft to reduce effect on wake turbulence and hence increasing capacity [5].

Different solutions proposed and models structured by scholars and institutions vary depends on which runway capacity factors have been looking on through and each airport particular consideration. The study will provides data and result from the previous research and perform a review on most influencing factor on runway capacity based on the data. The output generated expected to be used as reference in future studies in runway optimization.

2. Research Design
The paper designed in four steps: first, gathering definition of runway capacity from scholars perception; second, identifying parameters related to runway capacity and shortlisted into different categories; third, reviewing on previous research methods and analysis, and fourth, drawing conclusion from the research.

3. Definition of Runway Capacity
Runway capacity has a tight a relationship with airport performance to serve demand for air travel, and the inability of runway capacity to accommodate demand turns into one significant factor of delay. The problems related to runway capacity resolved with improving capacity number by additional runway or/and system improvement.

The correct perception of runway capacity and its significant factors needs to address precise solution of runway capacity problems. Definition on how scholars interpret general runway capacity tabulated in table 1 and may vary as a result of operation system, physical condition of airport and external factors.

Runway capacity is often divided into practical hour capacity, maximum throughput capacity, sustained capacity and declared capacity [6][7]. Practical hour capacity is defined as average movement number of aircraft on a runway per hour with accepted delay (4 minutes per operation); maximum throughput capacity is aircraft movement number with continuous demand; sustained capacity is average number of movements per hour that can be maintained for several hours; and declared capacity is capacity per hour, independently determined by the schedule coordination in each airport.
Table 1. Definition of Runway Capacity from Scholars.

| No | Source                                      | Definition                                                                 |
|----|---------------------------------------------|---------------------------------------------------------------------------|
| 1  | Pavlin et al, 2006 [8]                      | Maximum service rate and rely only on the physical and operational characteristic of runway and aircraft type. |
| 2  | Horonjeff, 2010 [9]                        | Maximum number of operation accommodated by facilities for some time period |
| 3  | Ashford et al, 2011 [10]                   | Maximum number of continuous operation of aircraft performed during certain time interval on a specific runway configuration under given weather condition and acceptable level of delay |
| 4  | OTA, 2012 [11]                             | Number of air operation that airport and ATC system could accommodate in a unit of time |
| 5  | Kolos-Lakatos et al, 2013 [12]             | Maximum possible number accommodated within certain time period for continuous demand for service |
| 6  | Airnav Indonesia, 2014 [13]                | Number of aircraft movements (departure and arrival) accommodated in certain time period based on configuration of runway, types of aircraft, percent touch and go, separation standard applied, supporting facilities and weather condition |
| 7  | Sawali et al, 2016 [14]                    | Ability of a runway to manage movements of aircraft (arrival and departure) in given unit of time |

4. Parameters Identification and Classification

As mentioned above, runway capacity may vary as a result of wide range of causative factors. Popular factor influencing runway capacity including: mix of aircraft types, runway occupancy time and separation between movements which then adapted by Airnav Indonesia to be implemented in Indonesian airports, while some of scholars derived each factor to get detailed significant factor.

To overcome the great number of factors/parameters related to runway capacity, this paper classify each parameters into five categories, adapted from main components of air transportation on dynamic capacity-demand balance research which are: operations/procedures, human factors, infrastructure/geometry, aircraft performance, flight plans according to Zhao et al. [15] and modified into: operations/procedures (flight plans categorized as operation), human factors, infrastructure/geometry, aircraft performance, external factors (several source mentioned external factors such as weather condition and noise).

Table 2 is constructed to get better and systematic classification system.

Table 2. Classification of Runway Capacity Factors.

| Category               | Description                                                                 |
|------------------------|-----------------------------------------------------------------------------|
| Operation/procedures   | Factors related to anything that makes activities functioned as addressed     |
| Geometry of airside facilities | Factors related to physical characteristic of airside facilities         |
| Aircraft performance   | Factors related to aircraft characteristic and its derivative               |
| Human factors          | Factor related to pilot, ATC officer and human related                      |
| External               | Factors excluding 4 categories above and unmanageable factors               |

Based on the classification system, the paper then collects parameter data from two kinds of sources: research result done by scholars and practical implementation in the form of case studies. Table 3 shows how each scholar has different result on significant parameter in influencing number of runway capacity.
| No | Source | Factor/Parameter | Category |
|----|--------|------------------|----------|
| 1  | Airnav Indonesia, 2014 [13] | Aircraft mix | Operation/procedures |
|    |        | Runway occupancy time | Operation/procedures |
|    |        | Separation between movements | Operation/procedures |
| 2  | Poldy, 1982 [16] | Separation standards | Operation/procedures |
|    |        | Aircraft characteristic | Aircraft performance |
|    |        | Runway configuration | Geometry of airside facilities |
|    |        | Movement mix | Operation/procedures |
|    |        | Air traffic control strategies | Human factors |
| 3  | FAA, 1983 [17] | Ceiling and visibility | External factors |
|    |        | Runway use configuration | Geometry of airside facilities |
|    |        | Aircraft mix | Operation/procedures |
|    |        | Percent arrival | Operation/procedures |
|    |        | Percent touch and go | Operation/procedures |
|    |        | Exit taxiway location | Geometry of airside facilities |
| 4  | Horonjeff, 2010 [9] | Runway geometry, including configuration, number, spacing and direction (orientation); Configuration of exit taxiways, including number and location; Gate number, size and arrangement in apron area; Runway Occupancy Time (ROT) for both of departure and arrival; Aircraft types and combination; Weather condition; Noise policy; Ratio between arrival and departure; Operator’s strategy under each weather and noise condition; Wake vortex separation; Navigation tool and procedures availability. | Geometry of airside facilities |
|    |        | | Operation/procedures |
| 5  | Pavlin et al, 2006 [8] | Apron number and dimension; Aircraft types using the facilities; Weather condition; Noise regulation; Procedures of ATC (Air Traffic Controller); Runway Occupancy Time (ROT). | Geometry of airside facilities |
|    |        | | Operation/procedures |
|    |        | | External factors |
|    |        | | Aircraft performance |
| 6  | Kolos-Lakatos et al, 2013 [12] | Wake vortex separation; Runway Occupancy Environment and noise | Operation/procedures |
| 7  | Sakif et al, 2015 [18] | Separation; Aircraft mix; Exit location configuration. | Operation/procedures |
| 8  | Buttler, 2008 [5] | In trail separation lateral separation | Operation/procedures |
| No | Source | Factor/Parameter | Category |
|----|--------|------------------|----------|
| 9  | Sawali et al, 2016 [14] | Sequencing and separation of departing and landing aircraft on intersect runway | Operation/procedures |
|    |        | Sequencing and separation of departing and landing aircraft on single runway | Operation/procedures |
|    |        | The sequencing of aircraft approaching airports located in close proximity to one another | Operation/procedures |
|    |        | Runway occupancy time | Operation/procedures |
|    |        | fleet mix | Operation/procedures |
|    |        | separation | Operation/procedures |
|    |        | reaction time of the pilot | Human factors |
| 10 | OTA, 2012 [11] | Aircraft performance characteristic | Aircraft performance |
|    |        | Wake vortex turbulence | Aircraft performance |
|    |        | Weather condition; | External factors |
|    |        | Airfield and airspace configuration | Geometry of airside facilities |
|    |        | Aircraft noise | Aircraft performance |
|    |        | ATC equipment and procedures | Operation/procedures |
|    |        | Demand consideration | Operation/procedures |
| 11 | Ashford et al, 2011 [10] | Meteorological condition | External factors |
|    |        | Airfield layout, runway configuration and operational strategy | Geometry of airside facilities |
|    |        | Aircraft arrival and departures ratio | Operation/procedures |
|    |        | Aircraft fleet mix | Operation/procedures |
|    |        | Runway occupancy time | Operation/procedures |
|    |        | ATC related factors | Operation/procedures |
| 12 | Bubalo et al, 2011 [19] | Local topography | External factors |
|    |        | Prevailing weather condition | External factors |
|    |        | Layout, configuration, availability of runway(s) | Geometry of airside facilities |
|    |        | Runway exits | Geometry of airside facilities |
|    |        | Taxiways | Geometry of airside facilities |
|    |        | Apron area | Geometry of airside facilities |
|    |        | Aircraft parking stands | Geometry of airside facilities |
|    |        | ATC capabilities | Operation/procedures |
5. Previous Study Method and Analysis
The different approach to deal with runway optimization based on various interests and condition of each airport system. Airnav Indonesia apply DORATASK method which calculating runway capacity based on actual time (take-off and landing time) and manage to improve capacity by reducing runway occupancy time, similar with research of Pavlin et al. [8]; while Horonjeff et al. [9], Kolos-Lakatos et al. [12], Buttler [5] and Sawali et al. [14] considering separation between aircraft plays an important role on runway capacity with deriving separation problems into different approach. The detail of method and stage taken by different scholars and airport presents on table 4.

| No | Source | Method | Point of Consideration | Stages |
|----|--------|--------|------------------------|--------|
| 1  | Airnav Indonesia, 2014 [13] | DORATASK Method | Runway Physical Capacity Calculation | a. Collecting Runway Occupancy Time (ROT) with field survey |
|    |        |        |                        | b. Calculating Arithmetical Mean ROT (AMROT) |
|    |        |        |                        | c. Calculating mix index for runway use |
|    |        |        |                        | d. Calculating Mean Runway Occupancy (MROT) |
|    |        |        |                        | e. Calculating Physical Capacity Runway (PCR) |
|    |        |        |                        | f. Calculating Aerodrome Physical Capacity (APC) |

Theoretical Runway Capacity Calculation

| Runway Physical Capacity Calculation | a. Collecting flight time for each type of aircraft between Outer Marker (OM) and threshold (THR) and calculating Mean |
| No | Source | Method                          | Poin of Consideration | Stages                                                                 |
|----|--------|---------------------------------|-----------------------|----------------------------------------------------------------------|
| 2  | Poldy, 1982 [16] | Intermovement Time (IMT) Matrix |                       | Flight Time (MT)                                                       |
|    |        |                                 |                       | b. Calculating average approach speed                                |
|    |        |                                 |                       | c. Determine Safety Separation (SS)                                   |
|    |        |                                 |                       | d. Determine total separation between 2 consecutive landing (TS)      |
|    |        |                                 |                       | e. Weighted time between 2 consecutive landing (MTTS)                 |
|    |        |                                 |                       | f. Determine number of landings in one hour interval (P)              |
|    |        |                                 |                       | g. Determine number of takeoffs in one hour interval (D)              |
|    |        |                                 |                       | h. Determine Theoretical Runway Capacity (TRC)                        |

Runway Declared Capacity Runway (DCR) Calculation

\[
DCR = \frac{UP_A \cdot TRC_A + UP_B \cdot TRC_B + \ldots}{UP_A + UP_B + \ldots}
\]

Intermovement Time (IMT) Matrix

Constructing pair probability matrix

\[
p_{ij} = A \cdot t_{AA} + D \cdot t_{DD}
\]

Calculating intermovement time for a sequence of movement during a busy period

\[
T = \sum_{ij} p_{ij} t_{ij}
\]
| No | Source | Method | Point of Consideration | Stages |
|----|--------|--------|------------------------|--------|
| 3  | FAA, 1983 [17] | FAA Method | FAA Method using secondary data with verification process, low cost, easily socialized, short period of survey | Calculating capacity $C = \frac{3600}{T}$
|    |        |        |                        | a. Runway-use configuration selection |
|    |        |        |                        | b. Identify figure number for capacity using figure released by FAA |
|    |        |        |                        | c. Determine percentage of Aircraft class C and D and calculate the mix index |
|    |        |        |                        | d. Determine percent arrivals |
|    |        |        |                        | e. Determine hourly capacity base ($C^*$) |
|    |        |        |                        | f. Determine the percentage of touch and go operation during VFR operation and determine touch and go factor ($T$) |
|    |        |        |                        | g. Determine the location of exit taxiways and determine the exit factor ($E$) |
|    |        |        |                        | h. Calculate the hourly capacity of the runway component by: Hourly capacity $= C^* \cdot T \cdot E$ |
| 4  | Horonjeff, 2010 [9] | Time-Space Concept | Spacing between aircraft considering as the most significant factor among others, hence time-space diagram used in time space concept is very useful and easy to understand | |
|    |        |        |                        | a. Two aircrafts may not conduct an operation on the runway at the same time. |
|    |        |        |                        | b. Arriving aircraft has a priority over departing aircraft |
|    |        |        |                        | c. Departures is allowed if the runway is clear and the subsequent arrival is at least a certain distance from the runway threshold |
| No | Source | Method | Point of Consideration | Stages |
|----|--------|--------|------------------------|--------|
| 5  | Pavlin *et al*, 2006 [8] | Reducing ROT concept | ROT considering as one of the most important factors related to runway capacity (increasing up to 15% capacity) | a. Calculating Runway Occupancy Time Arrival (ROTA) = time between threshold crossing and aircraft tail vacating the runway  
b. Calculating Runway Occupancy Time Departure (ROTD) = time between crossing the holding stop bar and main gear lifting off the runway |
| 6  | Kolos-Lakatos *et al*, 2013 [12] | Probabilistic queuing model, RECAT (Re-categorization) Traffic Mix model | Re-Categorization of aircraft based on wake turbulence after reduced separation minima considering effective in increasing capacity | a. Categorizing aircraft in six groups, range from A (largest commercially operating aircraft generating most severe wake turbulence) to F (small business jets and turboprops with weak vortices)  
b. Considering separation standard between aircraft category |

Figure 2 Time Space Diagram Concept for Mixed Operation
c. Calculating minimum time separation between leading and following aircraft $T_{ij}$

$$T_{ij} = \max \left( \frac{r + S_{ij}}{v_j}, ROT_i \right) \text{ when } v_i > v_j$$

- $r$: is the length of the final approach.
- $i$: is the leading airplane’s weight group.
- $j$: is the following aircraft’s group.
- $S_{ij}$: is the minimum required separation between the leading aircraft type and the following aircraft type.
- $T_{ij}$: is the minimum time interval between successive arrivals for aircraft $i$ and aircraft $j$.
- $v_i$: is the final approach velocity for the aircraft $i$.
- $v_j$: is the final approach velocity for the aircraft $j$.

d. Considering buffering time 19 sec

e. Calculating probability arrival pair

$$P_{ij} = 0.5 \times \text{(percentage of group)}$$

f. Calculating expected time an arrival pair takes to land

$$E(t) = \sum P_{ij} (T_{ij} + b)$$

g. Calculating RECAT capacity
| No | Source | Method | Point of Consideration | Stages |
|----|--------|--------|------------------------|--------|
| 7  | Sakif et al, 2015 [18] | Probabilistic model | $\mu = \frac{1}{E(t)} \times 3600 \text{sec/hour}$ | |
|    |        |        | $T_{ij} = \max \left[ \frac{r+s_{ij}}{v_j} - \frac{r}{v_i}, ROT_i \right]$ when $v_i > v_j$ | |
|    |        |        | $r$: is the length of the final approach. | |
|    |        |        | $i$: is the leading aircraft’s weight group. | |
|    |        |        | $j$: is the following aircraft’s group. | |
|    |        |        | $S_{ij}$: is the minimum required separation between the leading aircraft type and the following aircraft type. | |
|    |        |        | $T_{ij}$: is the minimum time interval between successive arrivals for aircraft $i$ and aircraft $j$. | |
|    |        |        | $v_i$: is the final approach velocity for the aircraft $i$. | |
|    |        |        | $v_j$: is the final approach velocity for the aircraft $j$. | |
| 8  | Buttler, 2008 [5] | NextGen Concept | NextGen represents automation in routine aspect of air traffic control, it will safely reduce separation between aircraft and permit more efficient routing of planes | |
| No | Source | Method | Point of Consideration | Stages |
|----|--------|--------|------------------------|--------|
| 9  | Sawali et al, 2016 [14] | Sequencing method | Sequence between two consecutive flights considering as the ost critical factor in runway capacity | a. Data input: flight number, aircraft departure, type of operation, scheduled time and runway use  
   b. Rule A: applicable for consecutive departure on the same runway  
   Rule B: applicable to all sequence with succeeding flight is arrival operation  
   Rule S: Any other sequence outside Rule A and Rule B |
| 10 | Ashford et al, 2011 [10] | Optimization model | Combine both analytical and empirical analysis, reliable and realistic | c. Input for algorithm  
   d. Output of the algorithm  
   e. Manual optimization |
| No | Source                  | Method  | Point of Consideration                                                                 | Stages                                                                                                                                 |
|----|-------------------------|---------|--------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|
|    | Bubalo et al, 2011 [19] | SIMMOD  | Possible to analyze and calculate airside capacity with complex and dynamic factors  |                                                                                                                                         |

Subject to:

\[ X_{i+1} = \max(0, X_i + u_i - a_i) \quad i \leq l \]

\[ Y_{i+1} = \max(0, Y_i + d_i - v_i) \quad i \leq l \]

\[ X_1 = X_0 \geq 0; Y_1 = Y_0 \geq 0 \quad \text{(given initial condition)} \]

\[ 0 \leq v_i \leq \Phi_i(u_i) \quad \Phi_i(u) \in \Phi \quad i \leq l \]

\[ 0 \leq u_i \leq B_i \quad i \leq l \]

Where:

- \( N \) = number of sequenced capacity curves
- \( a_i \) = arrival capacity at \( i \)th time slot
- \( b_i \) = departure capacity at \( i \)th time slot
- \( F \) = non-decreasing scalar function
- \( X_i \) = demand for departures at \( i \)th time slot
- \( Y_i \) = demand for arrivals at \( i \)th time slot
- \( \Phi_i(u) \) = arrival/departure capacity curve, which determines capacity at \( i \)th time slot
- \( \Phi \) = set of capacity curves that represent all runway configurations at all weather conditions

Input: combined flight schedule

Processed automatically with Visual SIMMOD Software package
6. Conclusions
Review on this study was based on review on runway capacity among scholars. Air transportation is an exclusive area in transportation world, the research conducted mainly for regulation need and held by government. The parameters related to runway capacity were gathered from various source, research paper, reports and books. The whole parameters collected were classified into five different categories: aircraft performance, geometry of airside facilities, operation/procedures, human factors and external factor to simplify further research.

The pie chart on figure 5 shows that operation/procedure related factors contribute the most on runway capacity (52 %). Derivation of operation/procedure factors will discuss separately.

![Figure 3. Parameters Related to Runway Capacity.](image)

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