Study of runway crosswind and tailwind potential for airport sustainability: A study of Soekarno Hatta airport, Cengkareng, Indonesia

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Abstract. Airport runway designs must consider wind climatology to reduce the potential for crosswind and tailwind events that can cause accidents and aircraft delays. The large potential of crosswind and tailwind on a runway at the airport is very detrimental to aircraft passengers and airlines. Therefore, it is necessary to know the potential of crosswind and tailwind on the runway of Soekarno Hatta Airport and find the right parameters for the approximate direction and speed of the wind on the airport runway. Analysis was carried out using the direction and wind speed data from the Soekarno Hatta meteorological station in 2007-2017 to determine the potential for crosswind and tailwind on the runway of Soekarno Hatta airport and run a Weather Research and Forecasting (WRF) weather model to determine the parameterization of the right weather model for wind forecast at Soekarno Hatta airport. The highest maximum crosswind component in the 2007-2017 period occurred in August 30.53 knots, while the highest maximum tailwind of 25 knots occurred in January for a 250-degree runway and 24 knots occurred in August for a 070-degree runway. The potential for crosswind and tailwind is different every month. The scheme produces forecasts of wind direction and speed with a strong level of correlation with observations of wind direction and speed from the Soekarno Hatta meteorological station, the correlation value is 0.61. The most significant social impact of plane delays is time loss for passengers. While the economic impact on one of the crosswind events at Soekarno Hatta airport was an economic loss for one airline of US $ 43,392.

Keywords: runway, crosswind potential, tailwind potential, numerical weather prediction, wind direction, wind speed, airport
1. Introduction

Runway is a significant factor in the aviation world, there are still very few studies assessing the feasibility of runway feasibility. This is exacerbated by the fact that the layout design and/or configuration of the runway has not been so complex even though the runway plays an important role in airport operations every day, concerning capacity and safety [1]. The runway design is very important to minimize disruption to flight including from weather factors. One very significant weather parameter on flights, especially takeoff and landing are wind. Wind direction and speed have a very significant effect on flight. Wind direction in the direction of the plane (tailwind) with significant wind speed is avoided by pilots when taking off and landing because it has the potential to cause the aircraft to slip or crash, as well as wind blowing from the side (crosswind). Conversely the opposite direction of the wind with the direction of movement of the aircraft will help the braking of the aircraft when landing and add lift to the takeoff process.

Data from the National Transportation Safety Committee (KNKT) shows that from 2012 to 2016, there is 69.91% of aircraft accidents in Indonesia occurred at airports. Accidents that occur at the airport are partly due to wind factors. With the windrose method, the average wind direction at an airport can be known to then become a reference for the construction of a runway with the least potential crosswind and tailwind.

In addition to the potential for accidents, crosswind and tailwind are also the cause of aircraft delays. According to data from the FAA, as much as 70 percent of flight delays are caused by weather factors, 15-20 percent are caused by aircraft traffic volumes that exceed the capacity of airports and airspace, and about 10 percent are caused by other problems such as the malfunctioning of air traffic control equipment and closure foundation [2]. The high potential of crosswind and tailwind of a runway is thus directly proportional to the potential for aircraft accidents or delays during the takeoff and landing processes. This is certainly a negative impact, especially economically for airlines and passengers. Wind analysis is essential in determining the direction of the runway. Aircraft that land and takeoff must be able to maneuver with cross situations wind though, so the maximum crosswind component should not occur on a runway. The runway direction of an airport should therefore be determined through graphical vector analysis, namely Windrose [3]. From the results of library research and information from the PT. Angkasa Pura II as the manager of Soekarno Hatta Airport, no climatology study of the wind was found to determine the direction of the Soekarno Hatta airport runway. This is not in line with the ICAO provisions which stipulate the wind study as a preliminary study of determining the direction of airport runways.

In addition to the study of wind climatology, wind direction and speed forecast from meteorological stations are also very important for pilots to avoid crosswind or tailwind during takeoff or landing. The results of the Soekarno Hatta meteorological station verification of the direction and wind speed forecast of the Soekarno Hatta airport for the period of January to July 2013 showed an accuracy of wind direction forecasts of 75% and wind speeds of 77%. These results are still below the minimum percentage determined by ICAO for aerodrome forecasts of 80% each for wind direction and speed. Determination of takeoff and landing direction is influenced by one of them by the direction of the wind blowing, so that the forecast of wind direction and speed in the form of flight meteorological information is needed at each airport, that is in accordance with the criteria of wind climatology is one of the supporting factors in the sustainability of the transportation sector development.

2. Literature review

Airport is that to land and take-off aircraft, boarding passengers and/or loading and unloading cargo and/or post and is equipped with aviation safety facilities and as a place of transfer between modes of transportation [4]. One of the main airport facilities whose role is very significant inflight safety is the runway. Determination of the runway position is very important in airport planning, as well as the direction of the runway which also greatly influences the configuration taxi routes, and other
infrastructure related to safety, and its anticipation for airport comfort. Currently, the construction of an airport runway considers:

1. wind conditions,
2. land availability and prices,
3. air barriers,
4. coordination with other airports,
5. noise impacts, and
6. conditions social and environmental.

From a number of factors above, due to the technicality of flight operations, wind conditions are the most important and very influential on aviation safety [5]. The world’s United Nations International Civil Aviation Organization (ICAO) have established standards that recommend runway designs in terms of average wind direction so as to allow aircraft to take off and land safely. According to FAA standards, runway orientation must allow aircraft to take off and land at least 95% without crosswind [6]. One of the airports in Indonesia which has a very crowded flight frequency is Soekarno Hatta Airport. Soekarno Hatta Airport has a land area of 1800 Ha with the provision of service facilities for 2 (two) runways with dimensions: 60 meters X 3660 meters and 60 meters X 3600 meters, runway direction 07 R, 25 L and 07 L, 25 R. Operational Soekarno Hatta airport is 24 hours. Soekarno Hatta Airport is located at coordinates 06° 07’ 49, 1080” latitude and 106° 39” 40,134” east longitude [7]. The number and letters of the runway are determined by the direction of the approach. The runway number is the tenth-degree number from the runway centerline, measured clockwise from magnetic north. The letter indicator to distinguish left /left for L, right / right for R and center / center for C. An airport that has 2 parallel runways uses L and R indicators, while airports that have 3 parallel runways use L, C and R [8].

Wind is the motion of air parallel to the surface of the Earth. Air moves from high pressure to low pressure areas. The wind is named according to the direction from which the wind comes, for example, the east wind is the wind coming from the east, the sea breeze is the wind that blows from the sea to the land, and the valley wind is the wind that comes from the valley up the mountains [9]. In accordance with ICAO and FAA provisions that planes take off and land in the direction of the wind. Headwind is a condition where the wind blows along the runway in the opposite direction to the direction of the plane. The headwind condition is recommended because it reduces the landing speed, while the tailwind is a condition where the wind blows in the direction of the plane that should be avoided because this condition will cause an increase in speed when landing so that it requires a longer runway [10]. Based on the theories that have been described, the theoretical framework in the research can be seen in Figure 1.

Figure 1. Theoretical Framework
Wind direction and speed data can also be input for making wind direction and speed forecast. The forecast wind direction and speed can be in the form of a numerical weather model that is used to determine the landing or take-off direction of the aircraft. Weather variables are constantly changing so that atmospheric models that represent real atmospheric conditions are then known as numerical weather prediction (NWP). NWP is not a physical model, but a mathematical model consisting of various mathematical equations to illustrate how temperature, wind, and humidity will change every time [11]. The theoretical framework begins with a theory of sustainable development that explains the development model to achieve sustainability in terms of economic, social, and environmental aspects. Sustainable development covers all sectors including the transportation sector.

3. Methodology
3.1. Research approaches and methods
The research applies a quantitative approach with the main method of windrose and numerical weather modeling. Windrose analysis is carried out to determine the potential for crosswind events, while numerical weather modeling is carried out to determine forecasts for crosswind events at the runway of Soekarno Hatta airport. The social and economic impact of the crosswind event is known through surveys of aviation companies.

3.2. Research variable
The research variables consist of:
1) Direction of the existing runway;
2) Wind direction;
3) Wind speed;
4) Crosswind component;
5) Components of the tailwind;
6) Runway direction with minimal crosswind and tailwind potential;
7) Economic losses due to crosswind and tailwind incidents;
8) Model of wind direction and speed.

3.3. Processing and data analysis
3.3.1. Windrose analysis
Stages of windrose analysis are done by finding the average direction and surface wind speed to determine the wind direction with significant dominant wind speed. The circles on the template show the wind speed, while the radial lines show the degree or direction of the wind gusts. Each cell is bounded by two circular segments and two radial lines (label A in Figure 2) that represent certain percentages of the period of wind direction and wind speed. The circle labeled B in the figure depicts the crosswind speed (for runway operations) smaller than the allowed crosswind [5]. Observation data of wind direction and speed from the Soekarno Hatta meteorological station from 1999 - 2019 will be used as input data for windrose analysis.

![Windrose Template](image-url)
The crosswind component is a resultant vector taken from the right angle of the runway. The value is calculated from the multiplication of the wind speed with the sinusoidal trigonometry between the wind direction and the runway [8]. Examples of crosswind component calculations are shown in Figure 3.

![Diagram of crosswind components](image)

**Figure 3. Example of Calculation of Crosswind Components [12]**

The results of the calculation of crosswind components are used to determine compatibility with crosswind components that are allowed to be seen from the runway design code (RDC) of each airport.

### 3.3.2. Social and economic impacts due to crosswind and tailwind

From the results of literature studies, it is known that the most significant social impact of airplane delays is the loss of time for both airlines and passengers. There are several time values to consider when assessing time losses due to plane delays [13]:

1. The value of travel time, this value considers the purpose of the trip (business or vacation), passenger income and duration of the trip;
2. Wait time value;
3. Time value when arrived sooner or later.

Previous studies have examined the social impact of aircraft delays using the cost approach. One of them is Morrison's study [2] which divides the value of passengers according to travel time based on the purpose of the trip. The study used data from the US Department of Transportation in 1995 to calculate the percentage of travel destinations for business, leisure and average household income for business and leisure. The results of the study resulted in an hourly passenger value for each delay of $40.16.

To calculate economic losses due to aircraft delays caused by crosswinds and tailwinds, a literature study was conducted on economic losses due to aircraft unity time delays. The economic loss value is then linked to aircraft delay data from selected airlines at Soekarno Hatta airport.

Garfield Eaton Ricondo & Associates, Inc. (2011), explain three cost components that must be paid by airlines to airport management consisting of airline fares and fees, airport direct costs, operating costs and delays. Westminster University (2004), reports one value of the average cost that must be incurred by each airline when experiencing delays. The calculation comes from about 42% of
flights in Europe with 12 types of aircraft. The average value produced is 72 euros per minute, with the following component breakdown (a value of 0 means that the cost is less than 0.5 euros):

4. Results and discussion

Based on the Soekarno Hatta airport runway design and wind direction and speed data for 10 years, the crosswind component from each runway is calculated. The runway direction for Soekarno Hatta airport is 070-degrees and 250-degrees. In accordance with the provisions of the FAA (2012), the crosswind component is a resultant vector taken from the right angle of the runway. The value is calculated from the multiplication between the wind speed and the sinusoidal trigonometry between the wind direction and the runway, as shown in Figure 4.

![Wind Class Frequency Distribution](image)

**Figure 4.** Graph of Wind Speed Percentage

4.1. Direction of Soekarno Hatta Airport's base with minimal tailwind potential

Previously, the crosswind and tailwind components are calculated at each runway. Runway 25 means that it is assumed that the aircraft landed or took off via a 250-degree runway and runway 07 means it was assumed that the aircraft landed or took off from a 070-degree runway. In addition to the crosswind component, the head wind and tailwind components are also counted. The minus value on the crosswind means that the crosswind is from the left side of the plane.

4.2. Forecast direction and wind speed of Soekarno Hatta Airport

Based on the output of the WRF-ARW model which has been downscaled to 1 km, there are four schemes which are obtained from the cumulus parameterization of the direction and wind speed for Soekarno Hatta airport. The forecast of wind direction and speed is used to determine the possibility of crosswind and tailwind events at Soekarno Hatta airport which are delivered in the form of flight meteorological information with an aerodrome forecast format to the pilot. The first scheme implemented was the Kain-Fritsch scheme.

In January 2007-2017 the maximum crosswind reached 18.39 knots, while the head wind was 11.82 knots if the aircraft landed or took off from the runway in 250-degrees and the head wind would be 25 knots if the aircraft landed or took off from 070-degrees. The highest maximum crosswind component in the 2007-2017 period occurred in August at 30.53 knots, while the highest maximum tailwind of 25 knots occurred in January for a 250-degree runway and 24 knots occurred in August for a 070-degree runway is presented in Figure 5.
4.3. Direction of Soekarno Hatta Airport’s base with minimal tailwind potential
The direction of the runway of Soekarno Hatta Airport with the potential for crosswind and tailwind is at least very dependent on the moon. From the comparison between the monthly windrose and the direction of the Soekarno Hatta airport runway, the current Soekarno Hatta airport runway which has a minimum wind potential is runway 07 with a potential tailwind of 4.2%. While runway 25 has a potential tailwind of 8.7%.

4.4. Validation of forecast of direction and wind speed at Soekarno Hatta Airport
To determine the accuracy of the forecast direction and wind speed output of the WRF model, validation is conducted between the model and the results of observing the direction and wind speed from the Soekarno Hatta meteorological station. The observations are taken from METAR news published by the Soekarno Hatta Meteorological station. METAR Soekarno Hatta Meteorological Station is made every hour for 24 hours per day, as shown in Figure 6.

Meanwhile, to compare the pattern of u and v components of the WRF model Kain-Fritsch scheme and observations of wind direction and velocity, graphs of u and v components are illustrated as shown in Figures 6 and 7, the pattern of component V models is closer to the V component observations compared between the components of the U model with respect to the U components of observation, presented in Figure 7.
The degree of relationship between wind models and observations is calculated using the correlation equation. Correlation of u component of the model and observation as well as the v component of the model and observation are as follows:

\[ ru = 0.24 \]
\[ rv = 0.64 \]

The correlation between the model and wind observations is calculated from the average correlation of components u and v. The resulting correlation value is \( r = 0.44 \). In accordance with the interpretation of the correlation value, the level of relationship between the wind model with the observation wind is moderate. To determine the error rate (error) of the model compared to the results of observations performed calculations Root Mean Square Error (RMSE). The RMSE value for component u is 3.74 and component v is 3.8, then the average RMSE value is 3.78 knots. The second scheme that is run on the WRF model parameterization for the direction and speed of the Soekarno Hatta airport is the Betts-Miller scheme. The pattern of component u and v between the WRF model of the Betts-Miller scheme with observations from the Soekarno Hatta meteorological station is shown in figures 6 and 7. From both images, it appears that the component pattern v model approaches the observation v pattern, but for the component u, the model pattern is not likely to be different from observation. To determine the error rate (error) of the model compared to the results of observations performed calculations Root Mean Square Error (RMSE). The RMSE value for component u is 3.74 and component v is 3.8, then the average RMSE value is 3.78 knots.

The second scheme that is run on the WRF model parameterization for the direction and speed of the Soekarno Hatta airport is the Betts-Miller scheme. The pattern of component u and v between the WRF model of the Betts-Miller scheme with observations from the meteorological station Soekarno Hatta is shown in Figure 6 and Figure 7. From both images, it appears that the component pattern v model approaches the observation v pattern, but for the component u, the model pattern is not likely to be different from observation.

To find out the parameterization of the WRF-ARW model that is most appropriate for predicting wind direction and speed of Soekarno Hatta airport, the relationship level and RMSE of the four parameterizations are compared. The comparison of the four parameterization schemes of the WRF-ARW model is shown in Table 1.
Table 1. Comparison of WRF Parameterization Schemes

| Scheme          | Corelation | Level of Relation | RMSE   |
|-----------------|------------|-------------------|--------|
| Kain-Fritsch   | 0.44       | normal            | 3.78 knot |
| Betts-Miller   | 0.61       | high              | 3.32 knot |
| Grell-Devenyi  | 0.32       | low               | 4.23 knot |
| Grell 3D       | 0.45       | normal            | 3.74 knot |

4.5. Social and economic impacts due to aircraft delay

The social impact of plane delays based on the literature study that has been presented in the previous chapter shows that loss of time is the most significant impact on airlines and passengers. The impact is then converted to the cost per unit time value. The value of 78.17 US dollars derived from the Airline for America report (2012) is used to calculate losses due to aircraft delays at Soekarno Hatta airport. By analyzing METAR data from the Soekarno Hatta meteorological station, a sample of high winds which caused a flight delay at Soekarno Hatta airport is taken. Aircraft delay data from one of the airlines operating at Soekarno Hatta airport. The calculation of costs due to aircraft delays is shown in Table 2.

Table 2. Flight Delay Fees at Soekarno Hatta Airport

| Flight Schedule (Time) | Actual (Time) | Delay time (Minutes) | Cost of delay ($) |
|------------------------|---------------|----------------------|-------------------|
| 11:00                  | 11:33         | 33                   | 2,580             |
| 11:00                  | 12:13         | 43                   | 3,361             |
| 11:00                  | 11:36         | 36                   | 2,814             |
| 11:00                  | 11:32         | 32                   | 2,501             |
| 11:15                  | 11:45         | 30                   | 2,345             |
| 11:20                  | 12:19         | 59                   | 4,612             |
| 11:20                  | 12:13         | 53                   | 4,143             |
| 11:20                  | 12:07         | 47                   | 3,674             |
| 11:30                  | 12:17         | 47                   | 3,674             |
| 11:30                  | 12:10         | 40                   | 3,127             |
| 11:30                  | 11:54         | 24                   | 1,876             |
| 11:40                  | 12:15         | 35                   | 2,736             |
| 11:45                  | 12:21         | 36                   | 2,814             |
| 11:45                  | 12:32         | 47                   | 3,674             |
| **Total**              |               |                      | **43,932**        |

The aircraft delay data in Table 2, is the plane delay on March 20, 2013. Based on observations from the Soekarno Hatta meteorological station, on March 20, 2013 at 11:00 WIB, the wind blows from 110 degrees at a speed of 18 km per hour. Airplane delay data from the airline shows that starting at 11:00 WIB, the company's aircraft are experiencing delays in both takeoff and landing. Schedule returned to normal since 11:45 WIB. The assumed loss of US $ 78.17 per minute is used to calculate the costs incurred by the airlines. With this assumption, the loss suffered by the airline concerned in one of the crosswind incidents at Soekarno Hatta airport is US $ 43,392.
5. Conclusion
There is potential for crosswind on the runway of Soekarno Hatta airport, especially from the south. However, with a maximum wind speed of 21 knots, the crosswind will not interfere with flights at Soekarno Hatta airport. The highest maximum crosswind component in the 2007-2017 period occurred in August at 30.53 knots, while the highest maximum tailwind of 25 knots occurred in January for a 250-degree runway and 24 knots occurred in August for a 070-degree runway. The most appropriate WRF weather model parameterization scheme for the forecast wind direction and speed at Soekarno Hatta airport is the Betts-Miller scheme. The scheme produces an estimate of the direction and speed of the wind with a strong level of correlation with observations of the direction and speed of the wind from the Soekarno Hatta meteorological station, the correlation value is 0.61. Crosswind and tailwind can cause aircraft delays. The most significant social impact of plane delays is time loss for passengers. While the economic impact on one of the passengers. While the economic impact on one of the

References
[1] Danyelle Lewis, P.A.L. 2012 Using A GIS-Based Approach and Wind Rose to Determine Runway Effectiveness and Study the Impacts of O’Hare Chicago International Airport, Thesis. Carbondale: University of Carbondale.
[2] Hofer C, Kali R, Mendez F 2018 Socio-economic mobility and air passenger demand in the U.S. Transportation Research Part A: Policy and Practice 112 85-94
[3] Ferrulli P 2016 Green Airport Design Evaluation (GRADE) Methods and Tools Improving Infrastructure Planning Transportation Research Procedia 14 3781-3790
[4] Department of Transportation. 2009 Regulation of the Director General of Civil Aviation Number SKEP / 124 / VI / 2009 of 2009 GUIDELINES FOR IMPLEMENTATION OF ENVIRONMENTALLY FRIENDLY AIRPORT (ECO AIRPORT)
[5] Sidiropoulos S, Majumdar A, Han K 2018 A framework for the optimization of terminal airspace operations in Multi-Airport Systems Transportation Research Part B: Methodological 110 160-187
[6] Benjamin D and Leibowicz 2020 Urban land use and transportation planning for climate change mitigation: A theoretical framework. European Journal of Operational Research 284 604-616
[7] Handrikovaro, M. 2012 Landscape Design of Terminal-3 Soekarno-Hatta International Airport, Thesis. Bogor: Institut Pertanian Bogor.
[8] Federal Aviation Organization (FAA) 2012 Advisory Circular AC 150/5300-13A. Airport Design.
[9] Taszarek M, Kendzierski S, Pilguj N 2020 Hazardous weather affecting European airports: Climatological estimates of situations with limited visibility, thunderstorm, low-level wind shear and snowfall from ERA5. Weather and Climate Extremes 28 100243
[10] Robinson S D 2019 Temporal topic modeling applied to aviation safety reports: A subject matter expert review. Safety Science. 116 275-286
[11] Saracoglu, A D, Sanli U. 2020 Effect of meteorological seasons on the accuracy of GPS positioning Measurement. 152 107301
[12] Santa S L B, Ribeiro J M P, Mazon G, Schneider J, Osório de Andrade Guerra J B S 2020 A Green Airport model: Proposition based on social and environmental management systems. Sustainable Cities and Society 59 102160
[13] Peñabaena-Niebles R, Cantillo V, Moura J L. 2020 The positive impacts of designing transition between traffic signal plans considering social cost. Transport Policy 87 67-76