Evaluation of hub-spoke airport networks in Sumatra island, Indonesia to increase efficiency of air transportation

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Abstract. Kualanamu International Airport is the busiest airport in Sumatra. In 2015, it served 8 million passengers and 41.6 thousand tons of goods for international and domestic flights. Hub-spoke networks are optimized when generally having a transport efficiency of at least 49-52% as well as providing air service in a wide geographic area and to many destinations. The aim of this study is to analyse the hub-spoke airport networks based on the Herfindahl-Hirschmann Index (HHI) to increase air transport efficiency in Sumatra Island. This study uses data from cargo production and couple’s flights from 10 airports in Sumatra Island for domestic flight route pairs and 6 airports for international flight route pairs. The results of the study show that route networks in Sumatra Island in existing conditions have not developed with the hub-spokes concept. The HHI analysis, indicates 2 hubs for domestic flights and 1 hub (Kualanamu) for international flights. Kualanamu International Airport and Hang Nadim International Airport were indicated as hub airports in Sumatra Island for domestic flights. The efficiency of air cargo transportation through the system (2 hubs and 8 spokes) results in a transport efficiency at 68.37%, which is still far above the efficient range at 49-52%.

1 Introduction

Kualanamu International Airport in Beringin, Deli Serdang Regency, North Sumatra Province is the 5th busiest airport in Indonesia and the busiest airport in Sumatra Island. Kualanamu International Airport opened to the public on July 25th, 2013. Kualanamu International Airport has served 6,374,897 passengers and 37,413,257 kilograms of cargo for domestic flights and 1,629,894 passengers and 4,215,927 kilograms of cargo for international flights [1]. Kualanamu International Airport’s service is expected to be equivalent with Sultan Aji Muhammad Sulaiman International Airport’s service which is

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the world's 14th best in Airport Service Quality by an Airport Council International survey among 79 airports with a passenger’s capacity between 5-15 million a year [2].

After the Airline Deregulation Act in 1978, domestic carriers have developed the hub and spoke structures for their operations to reduce the overall costs of air travel and to increase travel demand [3]. Many scholars have investigated ways to avoid the usual delays and inefficiencies incurred in landside, airside, and airline operations [4, 5, 6]. There are significant differences, however, between air-freight and the more intensively studied passenger business [7]. Traffic to air freight hubs and regional air express is likely to respond in fuel costs [8]. As in road transport, various methods have been tried to reduce transportation costs by applying congestion charges [9, 10], and identification of black spot locations to reduce accident costs [11]. The carrier can save fixed costs by forming a hub-spoke network [12]. The cost of accidents can be decreased by reducing accident frequency, injury severity [13] and determining speed limit [14]. Total accident cost in Purbalingga Regency, Central Java, Indonesia was estimated as 0.38% of the gross domestic product [15].

The flight coordination is less efficient and this is clearly reflected by the values of the flight coordination coefficient developed [16]. The aircraft arrival at the hub airport from the spokes airport is well-coordinated [17] The number of hub flights is based on the number of spokes and inter-connected cities [18]. Airline competition analysis in a hub and spoke system can be found in [19, 20]. For many combinations of origin zone and destination zone, travelers can choose between more than one main carrier and airport [21, 22]. Evaluation of performance air routes can be analyzed using network Data Envelopment Analysis (DEA) models [23]. DEA has been widely used in studies on the civil air aviation's efficiency analysis [23, 24, 25].

The aim of this paper is to evaluate the hub and spoke airport networks in Sumatra Island, Indonesia in existing conditions based on Herfindahl-Hirschmann Index (HHI) to identify air transport efficiency.

2 Method

2.1 Analysis approach

Costa proposes the Herfindahl-Hirschmann Index (HHI) method to measure the efficiency of airport networks that include the number of effective airports \( n_e \) and the number of hub airports \( h \) [26]. One meaningful measure of how well the On-Demand Air Service (ODAS) network meets the travel demand is the transport efficiency. This metric is defined by a set of network theory parameters, the exact derivation of which is beyond the scope of this paper, but which are admirably described by Newman in [27]. The first step in its calculation combines the ODAS network structure and the demand matrix into a weighted shortest path, given by Equation 1:

\[
l'_w = \frac{\sum j l_{ij} w_{ij}}{\sum j w_{ij}}
\]

Where \( l_{ij} \) is the shortest path between airport i and airport j (the number of flights required to link each airport i and airport j) and \( w_{ij} \) is the demand between airport i and airport j. Using Equation 1, the shortest path weighted by demand is computed leading to the average weighted shortest path of a given node, denoted by \( l'_{w} \). In this formulation, \( l'_{w} \) is
larger when demand is greatest between pairs with longer shortest path. This weighted shortest path is then converted (by means of reciprocal sum) to the transport efficiency:

\[ E_t = \frac{1}{N} \sum_{i} \frac{1}{l_{ij}^w} \]  

Where \( E_t \) is efficiency of transport, and \( N \) is the number of airports. The values of Equation 2 fall between zero and one. The value is one if inter-connections of each airport are direct flight routes or point-to-point.

In this case, the transporting efficiency of the ODAS network was 63%, which is quite good, considering that a large amount of the travel demand is met by ground transportation. As a comparison, hub and spoke networks generally have a transporting efficiency of 49-52%. This value also indicates that the topology of the ODAS network matches fairly well with the demand network, allowing a large number of travelers to be efficiently transported [27].

Based on the calculation of the Herfindahl-Hirschmann Index (HHI), the number of effective airport (\( n_e \)), and the number of hub airports (\( h \)). The formulas for calculating the HHI, \( n_e \), and \( h \) is as follows.

\[ \text{HHI} = \sum P_i^2 \]  
\[ P_i = \frac{x_i}{\sum x_i} \]

With \( x_i \) is the production of an airport.

Furthermore, determination of the number of hub airports (\( h \)) in the region is calculated by a formula as follows.

\[ h = \frac{0.5 \{n - (n^2 - (n^*n_e)^{1/2})\}}{} \]

\[ n_e = \frac{1}{\text{HHI}} \]

where \( n_e \) is the effective number of airports in the study area and \( n \) is the number of airports in the study area. After that, the transport efficiency (\( E_t \)) can be calculated using Equation 2.

### 2.2 Data collection

Required data for this study included the production data of each airport in Sumatra Island, the number of passengers boarding (people), the amount of cargo (kg) for domestic and international flights, the couple’s flights from 10 airports in Sumatra Island for domestic flight route pairs and 6 airports for international flight route pairs. Ten airports in Sumatra Island which analysis are Sultan Iskandar Muda International Airport in Banda Aceh, Kualanamu International Airport in Deli Serdang, Minangkabau International Airport in Padang, Sultan Syarif Kasim II International Airport in Pekanbaru, Hang Nadim International Airport in Batam, Depati Amir Airport in Pangkal Pinang, Sultan Thaha Airport in Jambi, Fatmawati Soekarno Airport in Bengkulu, Sultan Mahmud Badaruddin II International Airport in Palembang, and Radin Inten II (Branti) Airport in Lampung. Data from each of the airports was obtained from the Directorate General of Air Transportation, Ministry of Transportation Republic of Indonesia in 2017 [1].
3 Result and discussion

3.1 Herfindahl-hirschmann index (HHI) for domestic flights

The hierarchy of airports in Indonesia as referred to Ministry of Transportation Republic of Indonesia KM No. 11 (2010) in Article 9 (1) consists of hub airports and spoke airports [28]. HHI index calculation is done using Equation 3 and Equation 4 as stated in the method section. HHI analysis results showed that the amount of domestic cargo hub is required for distribution logistics/cargo in Sumatra Island, Indonesia is two airports. The three airports with the largest cargo production in Sumatra Island are (1) Kualanamu International Airport (37,413,257 kg), (2) Hang Nadim International Airport (33,035,468 kg), and (3) Sultan Mahmud Badaruddin II International Airport (11,854,587 kg). Herfindahl-Hirschmann Index (HHI) calculation can be seen in Table 1 for domestic flights from 10 airports in Sumatra Island, Indonesia.

<table>
<thead>
<tr>
<th>No.</th>
<th>Airport (IATA Code)</th>
<th>Cargo production (kg)</th>
<th>( P_i )</th>
<th>( P_i^{0.5} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sultan Iskandar Muda (BTJ)</td>
<td>3,572,254</td>
<td>0.02886</td>
<td>0.00083</td>
</tr>
<tr>
<td>2</td>
<td>Kualanamu (KNO)</td>
<td>37,413,257</td>
<td>0.30224</td>
<td>0.09135</td>
</tr>
<tr>
<td>3</td>
<td>Minangkabau (PDG)</td>
<td>9,372,979</td>
<td>0.07572</td>
<td>0.00573</td>
</tr>
<tr>
<td>4</td>
<td>Sultan Syarif Kasim II (PKU)</td>
<td>9,308,292</td>
<td>0.07520</td>
<td>0.00565</td>
</tr>
<tr>
<td>5</td>
<td>Hang Nadim (BTH)</td>
<td>33,035,468</td>
<td>0.26687</td>
<td>0.07122</td>
</tr>
<tr>
<td>6</td>
<td>Depati Amir/Pangkal Pinang (PGK)</td>
<td>6,671,234</td>
<td>0.05389</td>
<td>0.00290</td>
</tr>
<tr>
<td>7</td>
<td>Sultan Thaha (DBJ)</td>
<td>6,088,310</td>
<td>0.04918</td>
<td>0.00242</td>
</tr>
<tr>
<td>8</td>
<td>Fatmawati Soekarno (BKS)</td>
<td>2,034,146</td>
<td>0.01643</td>
<td>0.00027</td>
</tr>
<tr>
<td>9</td>
<td>Sultan Mahmud Badaruddin II (PLM)</td>
<td>11,854,587</td>
<td>0.09576</td>
<td>0.00917</td>
</tr>
<tr>
<td>10</td>
<td>Radin Inten II/Branti (TKG)</td>
<td>4,437,830</td>
<td>0.03585</td>
<td>0.00129</td>
</tr>
<tr>
<td></td>
<td>( \sum X_i ) 123,788,357</td>
<td>1.00000</td>
<td>0.19084</td>
<td></td>
</tr>
</tbody>
</table>

H HI 0.1908

\( n_e \) 5.2401

\( n \) 10

\( n^{0.5} - n_e. n \) 52.4009

\( (n^{0.5} - n_e. n)^{0.5} \) 6.8992

\( n - (n^{0.5} - n_e. n)^{0.5} \) 3.1008

\( 0.5 (n - (n^{0.5} - n_e. n)^{0.5} \) 1.5504

Number of hub airport 2

Based on the analytical results by Herfindahl-Hirschmann Index (HHI) in Table 1, there are two hub airports for the domestic flights in Sumatra Island. Hub airports that serve as a cargo hub are Kualanamu International Airport in North Sumatra and Hang Nadim
International Airport in Batam. The cargo production total for domestic flights from 10 airports in Sumatra Island, Indonesia is 123,788,357 kg.

The blueprint for National Logistics system development in Indonesia [29] associated with aspects of the implementation phase of air transport infrastructure includes: Phase I (2011-2015): An established international air hub in Jakarta, Kualanamu, and Makassar as well as operation of the system model 24/7 services for air cargo at Soekarno-Hatta International Airport.

### 3.2 Herfindahl-hirschmann index (HHI) for international flights

Herfindahl-Hirschmann Index (HHI) calculation for international flight from 6 airports in Sumatra Island, Indonesia can be seen in Table 2. The three airports with the largest cargo production in Sumatra Island are (1) Kualanamu International Airport (4,215,927 kg), (2) Hang Nadim International Airport (1,762,264 kg), and (3) Sultan Syarif Kasim II International Airport (1,179,191 kg). As for the composition of international cargo volume, freight across the airport that was examined only requires one hub, Kualanamu International Airport.

<table>
<thead>
<tr>
<th>No.</th>
<th>Airport (IATA Code)</th>
<th>Cargo production (kg)</th>
<th>P_i</th>
<th>P_i^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Sultan Iskandar Muda (BTJ)</td>
<td>80,241</td>
<td>0.00972</td>
<td>0.00009</td>
</tr>
<tr>
<td>2.</td>
<td>Kualanamu (KNO)</td>
<td>4,215,927</td>
<td>0.51044</td>
<td>0.26055</td>
</tr>
<tr>
<td>3.</td>
<td>Minangkabau (PDG)</td>
<td>784,875</td>
<td>0.09503</td>
<td>0.00903</td>
</tr>
<tr>
<td>4.</td>
<td>Sultan Syarif Kasim II (PKU)</td>
<td>1,179,191</td>
<td>0.14277</td>
<td>0.02038</td>
</tr>
<tr>
<td>5.</td>
<td>Hang Nadim (BTH)</td>
<td>1,762,264</td>
<td>0.21337</td>
<td>0.04552</td>
</tr>
<tr>
<td>6.</td>
<td>Sultan Mahmud Badaruddin II (PLM)</td>
<td>236,881</td>
<td>0.02868</td>
<td>0.00082</td>
</tr>
</tbody>
</table>

| ΣXi | 8,259,379 | 1.00000 | 0.33641 |

Based on the analytical results using Herfindahl-Hirschmann Index (HHI) in Table 2, only one hub airport for the international flights in Sumatra Island. Hub airport that serve as a cargo hub is Kualanamu International Airport in Deli Serdang, North Sumatra Province.

The total of cargo production for international flights from 6 airports in Sumatra Island, Indonesia is 8,259,379 kg. Kualanamu International Airport has the highest quantity of cargo production. The percentage of cargo volume in Kualanamu International Airport is 30.22% for domestic and 51.04% for international flights. The second position is Hang Nadim International Airport in Batam with a total cargo production of 33,035,468 kg (26.68%) for domestic flights and 1,762,264 kg (21.33%) for international flights.
3.3 Air transportation efficiency

The value of air transportation efficiency (Et) is between 0-1. The value of air transportation efficiency is 1 if interconnection between airports is a direct flight. The value of air transportation efficiency with hub and spoke system is efficient if the Et value is above the efficient range of 49-52% [27]. Number of hubs is one of the factors that affect the network structure of an airline [30]. Based on Herfindahl-Hirschmann Index (HHI), the quantity of domestic cargo hubs required for distribution logistics or cargo in Indonesia are two airports, the first being Soekarno-Hatta International Airport in Cengkareng, Banten [31] and the second being Juanda International Airport in Surabaya, East Java [32].

![Location of hub and spoke airport in Sumatra Island.](image)

The Herfindahl-Hirschmann Index (HHI) was used to calculate the efficiency of air transport for domestic flights. An efficient transport scheme is 2 hub airports and 8 spoke airports. The efficiency of air transport in the existing condition scheme is 68.37%. In this scheme, air transportation with a 2 hub airports and 8 spoke airports system is not efficient because the air transportation efficiency (Et) is already higher than 52%.
4 Conclusions

The route network in Sumatra Island in existing conditions has not developed with the hub and spokes concept. The Herfindahl-Hirschmann Index (HHI) analysis, indicates 2 hubs for domestic flights and 1 hub (Kualanamu) for international flights. Kualanamu International Airport and Hang Nadim International Airport are indicated as hub airports in Sumatra Island for domestic flights. The efficiency of air cargo transportation in the existing condition scheme with 2 hub airports and 8 spoke airports generates a transport efficiency ($E_t$) of 68.37%, which is still far above the efficient range of 49-52%.

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