Journal of Engineering and Applied Sciences 11 (8): 1804-1810, 2016
ISSN: 1816-949X

Hub and Spoke Airport Networks in Indonesia Based on Herfindahl-Hirschmann Index (HHI)

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Abstract: Soekarno-Hatta International Airport (SHIA) is the busiest airport in Indonesia and the 18th rank of the busiest airport in the world in 2015. In 2015 SHIA serving 54,053,905 passengers and 614,821 tons of goods to the amount of movement of aircraft as many as 1,059 per day. With this condition, there are some problems that arise delay occur during take-off and landing of aircraft, the airport becomes very crowded and busy. One of the efforts that can be done to perform air transportation network is determine the hub and spoke airports. The aim of this study is to analysis of hub and spoke airport networks in Indonesia based on Herfindahl-Hirschmann Index (HHI). At this existing scheme, these 34 flights at the airport In Indonesia were analyzed with a combination of 7 hubs and 27 spokes. Based on analysis of the Herfindahl-Hirschmann Index (HHI) produces two hubs for domestic flights and one hub for international flights. Two hub airports for the domestic flight are Soekarno-Hatta Airport and Sultan Hasanuddin Airport. Airport that serves as an international cargo hub is Soekarno-Hatta International Airport. The efficiency of air cargo transportation in existing condition scheme with 7 hub airports and 27 spoke airports generates an Efficiency of transport (E_t) 68.21%.

Key words: Hub and spoke, airport, Herfindahl-Hirschmann index, efficiency of transport, delay

INTRODUCTION

International air flights from and to Indonesia are concentrated at major airports like Soekarno-Hatta International Airport (SHIA) and Ngurah Rai International Airport. Soekarno-Hatta International Airport is the busiest airport in Indonesia and the 18th rank of the busiest airport in the world in 2015 (Airports Council International, 2016). In 2015, SHIA serving 54,053,905 passengers and 614,821 tons of goods and the amount of movement of aircraft as many as 1059 per day. In 2014, Soekarno-Hatta International Airport serving 61,155,625 domestic passengers, 12,553,436 international passengers and 592,646 tons of goods to the amount of movement of aircraft as many as 680 per day. The airport's airside capacity is almost exceeded. Number of aircraft movement at peak hour has been equal to runway capacity, namely 52 movements per hour. PT Angkasa Pura II, a national state company managing Soekarno-Hatta International Airport, mentioned that in year 2010, SHIA serves 61,197 international aviation and 244,344 domestic aviation. Total number of aircraft movement reaches 305,541 movements. In year 2014, aircraft movement is going to exceed runway capacity that is 370,000 movements (Haryanto, 2013).

Selection of air transport logistic distribution concept is one of the keys to success in the Master Plan for the Acceleration and Expansion of Indonesian Economic Development or Master plan Percepatan dan Perluasan Pembangunan Ekonomi Indonesia (MP3EI) year 2011-2025. The targets MP3EI are support the acceleration economic corridor Java as the center of industry and national services, strengthen national connectivity (local and global) and increased efficiency in transportation cost and logistics distribution

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effectiveness of air transport. In order to carry out a comprehensive evaluation from the air travel demand side, the present study considers an official document MP3EI or Master Plan for the Acceleration and Expansion of Indonesia Economic Development year 2011-2025. MP3EI is a current and most priority economic policy referred by Indonesia Coordinator Ministry of Economy in 2011. With this condition, there are some problems that arise delay occur during take-off and landing of aircraft, the airport becomes very crowded and busy. Insufficient number of infrastructures, transportation costs that lead to high economic costs and limited network and capacity are the problems in logistics service. One of the efforts that can be done to perform air transportation network is determine the hub and spoke airports. A hub and spoke system is a system of air transportation in which local airports offer air transportation to a central airport where long-distance flights are available.

At early stage, planning of an airfreight transportation network should consider to the existing conditions of airport infrastructure, warehousing and logistics demand. Therefore, an analysis can be made to determine the best-suited type of aircraft and location of logistics centers which provide the highest efficiency. However, the infrastructure should be considered as the object of planning in which it plays role as an input to the development of air transport infrastructure (Sugiyanto *et al*., 2015). The growth of hub and spoke networks has allowed medium and large size airports that limited in passenger demand in the catchment area to become the primary hubs in their respective regions (Wu *et al*., 2011). Herfindahl-Hirschmann Index (HHI) is one of the methods to analysis the hub and spoke airport networks. The aim of this study is to analysis of hub-and-spoke airport networks in Indonesia based on Herfindahl-Hirschmann Index (HHI).

Literature review

Hub and spoke network: A hub and spoke network is a route system in which flights from many spoke cities fly into a central hub city. A key element of this system is that the flights from the spokes all arrive at the hub at about the same time so that passengers can make timely connections to their final destinations. An airline must have access to enough gates and takeoff and landing slots at its hub airports in order to handle the peak level of activity (Bauer, 1987). Hub and spoke network pattern occurs when all flights are directed to the great central location and then the passengers change their flights to reach their final destination (Dennis, 1994).

Hub and spoke network pattern has been introduced and developed in the aviation world in the United States since the early 1980s, triggered by the enforcement of the Airline Deregulation Act in the USA in 1978 (Dennis, 1994) which promoted considerable deployment of the hub and spoke network structures for the airports and airlines operations worldwide and contributed also to the overall costs' reduction both for passenger and air cargo traffic. Over the past twenty years since the enactment of the Airline Deregulation Act (ADA) of 1978, new airlines were permitted to enter the industry and all airlines could choose the routes they would serve and the fares they would charge (Bauer, 1987), the major US domestic carriers have developed hub and spoke structures for their operations. These have been instrumental in helping to reduce the overall costs of air travel and to increase the travel options that are available. The carrier can save the fixed cost by forming the hub-spoke network (Morimoto and Teraji, 2013).

Airfreight transportation has undergone significant changes since the general trend towards market liberalization began in the late 1970s. There are significant differences, however, between the airfreight and the more intensively studied passenger businesses (Kim and Park, 2012). In the past ten years many scholars have probed how to avoid the usual delay and in-efficiency incurred in airside, landside and airlines operations (Hansen, 2002; Yan *et al*., 2002; Wu and Caves, 2002).

Herfindahl-Hirschmann Index (HHI): One meaningful measure of how well the On Demand Air Service (ODAS) network meets the travel demand is the transporting 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 in Fry and DeLaurentis (2008). The first step in its calculation combines the ODAS network structure and demand matrix into a weighted shortest path given by:

$$l_w^i = \frac{\sum_j l_{ij} w_{ij}}{\sum_j w_{ij}} \quad (1)$$

Where:

l_{ij} = Shortest path between airport i and airport j (the number of flights required to link each airport i and j)

w_{ij} = The demand between airport i and airport j

Using Eq. 1, the shortest path weighted by the demand is computed leading to the average weighted shortest path of a given node, denoted by l_w^i. In this formulation, l_w^i 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 transporting efficiency:

$$E_t = \frac{1}{N}\sum_i \frac{1}{l_i^w} \quad (2)$$

Where:
E_t = Efficiency of transport
N = the number of airport

The values of Eq. 2 fall between zero and one. The value is one if inter-connected of each airport is direct flight route 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 (Fry and DeLaurentis, 2008).

MATERIALS AND METHODS

Analysis approach: 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 equations for calculating the HHI, n_e and h is as follows:

$$HHI = \sum P_i^2 \qquad P_i = x_i / \sum x_i \quad (3)$$

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:

$$h = 0.5\ \{n-(n^2-(n\times n_e)^{1/2}\} \qquad n_e = 1/HHI \quad (4)$$

with 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 calculating the efficiency of transport (E_t) using Eq. 2.

Data collection: Data required includes the production data of each airport, the number of passengers boarding (people), number of cargo (kg) for domestic and international flights, these couple's flights from 34 airports for domestic flights and 19 airports for international routes pair. Data production of each of the airports is obtained from the Ministry of Transportation Republic of Indonesia in 2016.

RESULTS AND DISCUSSION

Costa *et al*. (2010) proposes Herfindahl-Hirschmann Index (HHI) method to measure the efficiency of airport networks that include number of airport effective (n_e) and number of hub airport (h).

Hierarchy of airport: Hierarchy of airport in Indonesia is classified into four levels, i.e., primary hub, secondary hub, tertiary hub and spoke. The hierarchy of 34 airports in Indonesia is shown in Fig. 1. From Fig. 1, eight airports include primary hub i.e. Soekarno-Hatta International Airport Jakarta, Juanda International Airport Surabaya, Kuala Namu (Polonia) International Airport, Hang Nadim International Airport Batam, Ngurah Rai International Airport Denpasar, Sultan Aji Muhammad Sulaiman (Sepinggan) International Airport Balikpapan, Sultan Hasanuddin International Airport Makassar and Sam Ratulangi International Airport Manado. There are 14 airports that include secondary hub, 12 airports that include tertiary hub and Halim Perdanakusuma airport is a spoke.

Hierarchy of airports in Indonesia as referred to KM No. 11 in Article 9 (1) consists of hub airport and spoke airport. Hub airport is an airport that has a broad coverage of various service airport serving the passenger and/or cargo and influence the development of the national economy or the provinces. Spoke airport is airports that has service coverage and affect the development of the local economy, destination airport and supporting infrastructure service local activities. Desire line of air passenger in Indonesia is shown in Fig. 2. Hub airport consists of primary hub, secondary hub and tertiary hub.

Primary hub is airports with a scale of primary service such as one of the airport infrastructure service supporting the National Events Centre or Pusat Kegiatan Nasional (PKN) to serve passengers with a number ≥5,000,000 (5 million) per year. Secondary hub is airports with a scale of secondary services such as airport as one of its supporting infrastructure services the National Events Centre or Pusat Kegiatan Nasional (PKN) to serve passengers with a number ≥1,000,000 (1 million) and <5,000,000 (5 million) people per year. Tertiary hub is airports with a scale of tertiary service that the airport as one of the supporting infrastructure National Event Center service or Pusat Kegiatan Nasional (PKN) and the Regional Activity Centre or Pusat Kegiatan Wilayah (PKW). Tertiary hub serve passengers with a number greater than ≥500,000 (5 hundred thousand) and <1,000,000 (one million) people per year.

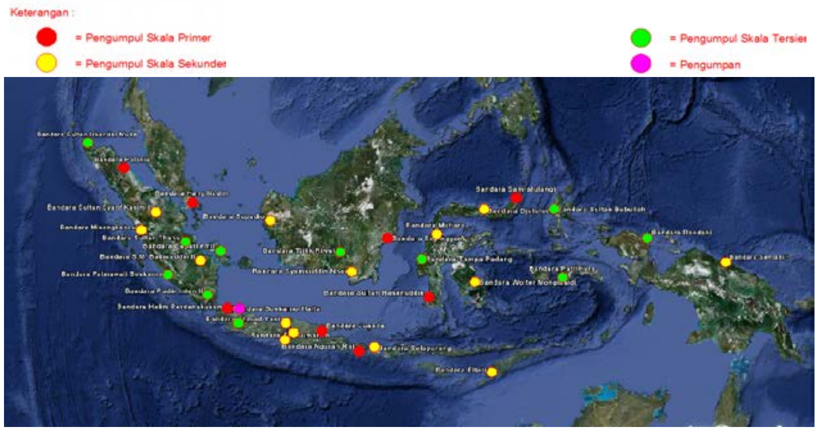

Fig. 1: Hierarchy of airport in Indonesia (Sugiyanto *et al*., 2015)

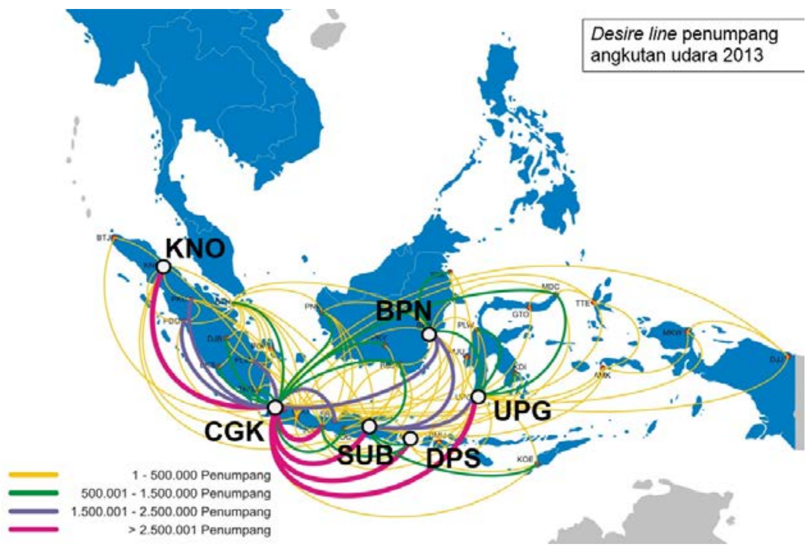

Fig. 2: Desire line of air passenger in Indonesia

Herfindahl-Hirschmann Index (HHI): HHI index calculation is done with the equation as stated in the methodology study. HHI analysis results showed that the amount of domestic cargo hub is required for distribution logistics/cargo in Indonesia are two airports. Two airports with the largest cargo production Soekarno-Hatta International Airport and Juanda International Airport. The airport with the amount of cargo that is quite close to the third rank is Sentani Airport. As for the composition of the volume of international cargo freight across the airport that were examined for the moment only requires one hub. The hub is the Soekarno-Hatta International Airport. This approach is quite different from the above considerations Freight Ratio (FR) value where possible international cargo hub is Hang Nadim Airport and Sepinggan Airport. Herfindahl-Hirschmann Index (HHI) calculation can be seen in Table 1 for domestic flights from 34 airports in Indonesia and Table 2 for international flights from 19 airports in Indonesia.

Based on the analytical results by Herfindahl-Hirschmann Index (HHI) in Table 1, there are two hub airports for the domestic flight. Hub airports that serve as a national cargo hub is Soekarno-Hatta International Airport in Cengkareng and Sultan Hasanuddin International Airport in Makassar. The developments of air transport logistic according to Blueprint for Development of the National Logistics System 2011-2025 (Peraturan Presiden Republik Indonesia No. 26, 2012) are:

Table 1: HHI calculation for domestic flight

Airport	Cargo production (kg)	P_i	P_i^2
Sultan Iskandar Muda	3,572,254	0.00474	0.00002
Kuala NamuD	37,413,257	0.04959	0.00246
Minangkabau	9,372,979	0.01242	0.00015
Sultan Syarif Kasim II	9,308,292	0.01234	0.00015
Hang Nadim	33,035,468	0.04379	0.00192
Depati Amir	6,671,234	0.00884	0.00008
Sultan Thaha	6,088,310	0.00807	0.00007
Fatmawati Soekarno	2,034,146	0.00270	0.00001
S.M. Badaruddin II	11,854,587	0.01571	0.00025
Radin Inten II (Branti)	4,437,830	0.00588	0.00003
Husein Sastranegara	6,401,393	0.00849	0.00007
Soekarno-Hatta	288,410,185	0.38229	0.14615
Ahmad Yani	11,008,548	0.01459	0.00021
Adi Sumarmo	2,841,117	0.00377	0.00001
Adi Sutjipto	10,477,826	0.01389	0.00019
Juanda	31,763,155	0.04210	0.00177
Ngurah Rai	17,680,795	0.02344	0.00055
Selaparang	6,536,373	0.00866	0.00008
Eltari	2,241,050	0.00297	0.00001
Supadio	2,495,401	0.00331	0.00001
Tjilik Riwut	3,587,391	0.00476	0.00002
Syamsuddin Noor	11,533,966	0.01529	0.00023
Sultan Aji Muhammad Sulaiman (Sepinggan)	25,926,867	0.03437	0.00118
Juwata	6,888,095	0.00913	0.00008
Sam Ratulangi	5,378,145	0.00713	0.00005
Djalaluddin	2,295,757	0.00304	0.00001
Mutiara	3,075,858	0.00408	0.00002
Tampa Padang	21,488	0.00003	0.00000
Sultan Hasanuddin	52,491,364	0.06958	0.00484
Wolter Monginsidi	3,123,571	0.00414	0.00002
Pattimura	3,168,744	0.00420	0.00002
Sultan Babullah	1,692,400	0.00224	0.00001
Sentani	130,616,171	0.17313	0.02998
Rendani	978,148	0.00130	0.00000
ΣX_i	754,422,165	1.00000	0.19065

HHI = 0.19065; n_e = 5.24521; n = 34; n^2-n_e.n = 977.66273; $(n^2-n_e.n)^{0.5}$ = 31.26760; $n-(n^2-n_e.n)^{0.5}$ = 2.73240; 0.5 $(n-(n^2-n_e.n)^{0.5}$ = 1.36620; Number of hub = 2

- Period 2011-2015: Strengthening Domestic Logistics System
- Period 2016-2020: Integration of ASEAN Logistics Network
- Period 2021-2025: Global Logistics Network Integration

Blueprint for National Logistics has associated with aspects of the implementation phase of air transport infrastructure include: Phase 1 (2011-2015): An established international air hub in Jakarta, Kuala Namu and Makassar and operation of the system model 24/7 services for air cargo at Soekarno-Hatta International Airport. (Table 2). Based on the analytical results by Herfindahl-Hirschmann Index (HHI) in Table 2, there is one hub airport for the international flight. Airport that serves as an international cargo hub is Soekarno-Hatta International Airport. The total of cargo production for domestic flight from 34 airports in Indonesia is 754,422,165 kg and for the international flight is 370,240,491 kg.

Table 2: HHI calculation for international flight

Airport	Cargo production (kg)	P_i	P_i^2
Sultan Iskandar Muda	80,241	0.00022	0.00000
Kuala Namu	4,215,927	0.01139	0.00013
Minangkabau	784,875	0.00212	0.00000
Sultan Syarif Kasim II	1,179,191	0.00318	0.00001
Hang Nadim	1,762,264	0.00476	0.00002
S.M.Badaruddin II	236,881	0.00064	0.00000
Husein Sastranegara	868,709	0.00235	0.00001
Soekarno-Hatta	326,411,673	0.88162	0.77726
Ahmad Yani	244,555	0.00066	0.00000
Adi Sumarmo	138,269	0.00037	0.00000
Adi Sutjipto	605,414	0.00164	0.00000
Juanda	21,864,736	0.05906	0.00349
Ngurah Rai	8,759,059	0.02366	0.00056
Selaparang	93,489	0.00025	0.00000
Supadio	8,774	0.00002	0.00000
Sepinggan	1,826,915	0.00493	0.00002
Juwata	12,801	0.00003	0.00000
Sam Ratulangi	164,111	0.00044	0.00000
Sultan Hasanuddin	982,607	0.00265	0.00001
ΣX_i	370,240,491	1.00000	0.78151

HHI = 0.78151; n_e = 1.27957; n = 19; n^2-n_e.n = 336.68809; $(n^2-n_e.n)^{0.5}$ = 18.34906; $n-(n^2-n_e.n)^{0.5}$ = 0.65904; 0.5 $(n-(n^2-n_e.n)^{0.5}$ = 0.32547; Number of hub = 1

Soekarno-Hatta International Airport has the highest of cargo production. The percentage of cargo volume in Soekarno-Hatta International Airport is 38.23% for domestic flight and 88.16% for international flight. The second position is Sentani Airport in Papua with total of cargo production is 130,616,171 kg (17.31%) for domestic flight and Juanda International Airport with the total of cargo production is 21,864,736 kg (5.91%) for international flight.

Transport efficiency analysis: The value of air transportation Efficiency (E_t) between 0-1. The value of Et is 1 if inter-connected every airport is direct flight. The value of air transportation efficiency with hub-spoke system is efficient if the Et value between 49-52%. One of the methods to analysis the air transportation efficiency (E_t) is Herfindahl-Hirschmann Index (HHI).

The scenario to analyses transport efficiency is in existing condition scheme with 7 hub airports and 27 spoke airports. On this scheme, the location of the hub and spoke is to follow with the existing conditions and analyzed until 2016. There are seven hub airports are Kuala Namu Airport (before, 2014), Soekarno-Hatta International Airport, Juanda International Airport, Sultan Aji Muhammad Sulaiman (Sepinggan) International Airport and Sultan Hasanuddin International Airport. Using the Herfindahl-Hirschmann Index (HHI) to calculate the efficiency of transport. Efficiency of transport for this scheme may be shown in Table 3 and Fig. 3. The value of

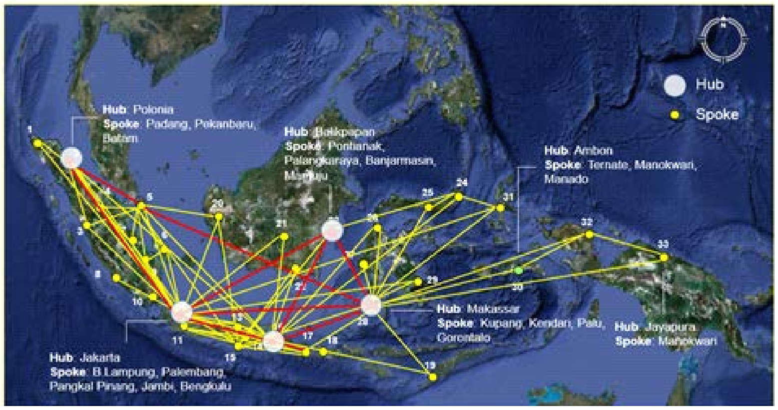

Fig. 3: Movement pattern of air cargo transport in Indonesia

Table 3: Efficiency of transport (E_t)

Hub airport	Spoke airport
Kuala Namu	Sultan Iskandar Muda, Minangkabau, Sultan Syarif Kasim II, Hang Nadim, Depati Amir
Soekarno-Hatta	Supadio, Husein Sastranegara, Ahmad Yani, Adi Sutjipto, Radin Inten II (Branti), S.M. Badaruddin II, Fatmawati Soekarno, Sultan Thaha
Juanda	Adi Sumarmo, Ngurah Rai, Selaparang, Eltari
Sultan Aji Muhammad Sulaiman (Sepinggan)	Tjilik Riwut, Sam Ratulangi, Syamsuddin Noor, Juwata
Sultan Hasanuddin	Djalaluddin, Mutiara, Tampa Padang, Wolter Monginsidi
Pattimura	Sultan Babullah
Sentani	Rendani
$\Sigma(1/l_w)$	23.193
N	34
1/N	0.0294
$E_t = (1/N)*(\Sigma 1/l_w)$	68.21%

weighted shortest path is 23.193, the number of airport is 34 get the efficiency of transport in existing condition scheme is 68.21%. In this scheme, air transportation with 7 hub airports and 27 spoke airports system is not efficient because the number of air transportation efficiency (E_t) >52%.

Airfreight transport efficiency analysis was conducted to determine the level of efficiency of the hub and spokes that run today and hub and spoke according to the scenario proposed by National Logistics System or Sistem Logistik Nasional (Sislognas) and KM 11 (2010). Based on National Logistics System or Sislognas for the phase 1: an established international air hub in Soekarno Hatta in Jakarta, Kuala Namu in Medan and Sultan Hasanuddin in Makassar. The advantages of hub-and-spoke are consolidation of passengers (economies of density), decreased number of routes, increase demand (frequent flights), consolidation of activities (personnel, maintenance, etc.,) and decrease costs. Traffic to regional air express and airfreight hubs is likely to respond in complex ways to fuel costs (Kelly, 2014). Punctuality of air traffic is one of the most important criteria for choosing an air service (Ha *et al*., 2015). In aerospace, systems analysis generally refers to the process whereby new systems are developed and evaluated in order to determine their appropriateness to a given operating environment (Fry and DeLaurentis, 2008).

CONCLUSION

The flight route in Indonesia has not been fully developed in accordance with the concept of hub and spoke airport network. Based on analysis with the Herfindahl-Hirschmann Index (HHI) method produces two hub for domestic flights and one hub for international flights. Two hub airports for the domestic flight are Soekarno-Hatta Airport and Sultan Hasanuddin Airport. Airport that serves as an international cargo hub is Soekarno-Hatta International Airport. The efficiency of air cargo transportation in existing condition scheme with 7 hub airports and 27 spoke airports generates an efficiency of transport (E_t) 68.21%.

ACKNOWLEDGEMENTS

This research was carried out by the financial support of Directorate of Research and Community Services, Ministry of Research, Technology and Higher Education, Republic of Indonesia through Research Grant "Hibah Penelitian Prioritas Nasional (PENPRINAS) Master Plan Percepatan dan Pembangunan Ekonomi Indonesia (MP3EI) 2011-2035" or "the research grant under a scheme of National Priority Research of Master plan for the Acceleration and Expansion of Indonesia Economic Development 2011-2035" in the fiscal year 2015-2016. All the contributions are acknowledged.

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