Journal of Transport Geography 68 (2018) 67–77

Contents lists available at ScienceDirect

Journal of Transport Geography

journal homepage: www.elsevier.com/locate/jtrangeo

The evolving structure of the Southeast Asian air transport network through the lens of complex networks, 1979–2012

Liang Dai[a], Ben Derudder[a,*], Xingjian Liu[b]

[a] Department of Geography, Ghent University, Krijslaan 281/S8, Gent 9000, Belgium
[b] Department of Urban Planning and Design, The University of Hong Kong, 8/F, Knowles Building, Pokfulam Road, 999077, Hong Kong

A R T I C L E I N F O

Keywords:
Complex network
Air network
Topology
Multilayered structure
Southeast Asia

A B S T R A C T

This paper presents a novel approach to investigating and understanding the evolving structure of the Southeast Asian air transport network (SAAN) over the period 1979–2012. Our approach captures the main topological and spatial changes from a complex network perspective. We find that the SAAN combines a relatively stable topological structure with a changing multilayered geographical structure. Statistical analysis indicates that the SAAN is a scale-free network with an increasing number of hub cities and has been characterized by small-world properties since 1996. Furthermore, the SAAN exhibits a recently intensified disassortative mixing pattern, suggesting an increasing dependence of small cities on hub-and-spoke configuration for better accessibility. A decomposition analysis is used to disaggregate the SAAN into a hierarchical core-bridge-periphery structure. The core layer consists of capital cities, the most economic vibrant secondary cities, and tourist destinations. This core layer is also densely interconnected with its center of gravity moving towards the north. The periphery layer, comprised of cities in remote areas, sustains a low significance with declining internal connectivity despite a rising number of cities being connected. The bridge layer lies in between both extremes, and is characterized by a high volatility over time. The connections and passengers between different layers increase, especially those between core and bridge after 1996. In our discussion, we trace these changes back to a series of socio-economic and politico-institutional dynamics in Southeast Asia.

1. Introduction

Air transportation has emerged as a key facilitator of economic development and social change as it greatly enables the flow of people, goods, capital, and information across space. This is particularly true for Southeast Asia (SEA), one of the most economically dynamic and strategically significant regions in the global economy (Sien, 2003). In 2015, SEA, which is commonly defined as including Cambodia, Laos, Myanmar, Vietnam (CLMV), Thailand, Malaysia, Singapore, Indonesia, Philippines, Brunei, and East Timor (formerly part of Indonesia) (cf. Rimmer and Dick, 2009), ranked third in Asia both in terms of its population of 633 million inhabitants (following China and India) and in terms of its economic size with a combined gross domestic product (GDP) of US$2.45 trillion (following China and Japan) (ASEAN Secretariat, 2016). Important from the perspective of air transport, the region is much more geographically fragmented than, say, the European Union (EU) and North America. The archipelagic geography, further complicated by often-difficult terrain to cross in climatic and physiographic terms, endows air transportation with competitive advantages over road, rail, and water transportation (Zhang et al., 2008). Or, as O'Connor (1995: 270) has pointed out: "air transportation is the only effective means for intercity links" in this region. For example, an express coach covering the 250 km trip from Ho Chi Minh City to Phnom Penh takes at least 5.5 h, whereas the flying time is only 45 min. Meanwhile, travelling by rail from Bangkok to Kuala Lumpur takes about 24 h compared to a 2-h flight. Similarly, a ferry trip between Singapore and Jakarta via Batam can last 26 h while a flight takes < 2 h. As a consequence, the importance of developing efficient and extensive air transport networks has been highlighted in various regional and national policy agendas (ASEAN Secretariat, 2011).

After several decades of fast-paced development, the Southeast Asian air transportation system has evolved into a complex network with mixed structures and large heterogeneities in capacity and intensity of connections. However, to date there has been no effort to engage in systematic complex-network analysis of the Southeast Asian air transport network (SAAN). Such a complex network approach has been shown to provide new insights into air transport systems at national (e.g., China; Wang et al., 2011), macro-regional (e.g., the EU;

* Corresponding author.
E-mail addresses: liang.dai@ugent.be (L. Dai), ben.derudder@ugent.be (B. Derudder), xliu6@hku.hk (X. Liu).

https://doi.org/10.1016/j.jtrangeo.2018.02.010
Received 6 October 2017; Received in revised form 20 February 2018; Accepted 21 February 2018
Available online 02 March 2018
0966-6923/

Zanin and Lillo, 2013), and global (e.g., Guimera et al., 2005) scales. An analysis of the SAAN may or may not reach similar conclusions, as it entails very different sets of underlying geographic, institutional, and socioeconomic factors (Lordan and Sallan, 2017). To help filling this gap, in this paper we explore the structural evolution of the SAAN during 1979–2012 from a complex network perspective.

When examining a supra-national region such as the SEA region, one obviously risks falling into the 'territorial trap' (Agnew, 1994; Bunnell, 2013): it can be argued that the crux of the geographies of SEA's air transport connections are not simply confined to the SEA region, thus challenging the a priori framings such as SEA and ASEAN (cf. Taylor et al., 2013). Indeed, the 'openness' of SEA is clearly visible in the possible extension of the system to Hong Kong (Dick, 2005), or in the identified functional airline region by including neighboring China and Japan (Guimera et al., 2005). However, there has been no consensus on how closed a transport or urban system should be to make a regional framing tenable (Kratoska et al., 2005), while the liberalization/deregulation geography as circumscribed by the move towards open skies in the in the context of ASEAN Economic Community (AEC) and ASEAN Single Aviation Market (ASAM) does lend the region a certain coherence in this context (Liu et al., 2017; Thompson, 2013). Our analysis will therefore focus on airline connections originating and terminating within SEA.

The main contributions of our study are twofold. First, we conduct a statistical analysis to characterize the evolving topological structure of the SAAN over this 34-year period and compare the network metrics with some other major regional blocs. Second, a decomposition technique is employed to unveil the multilayered structure of the SAAN for the years 1979, 1996 and 2012, respectively. By doing so, we shed light on how the topological and geospatial architecture of the SAAN changes over time. To this end, the remainder of this paper is organized as follows: Section 2 reviews the literature, focusing on the application of complex network theory in the study of the geography of air transport networks. This is followed by a discussion of our methodological framework and data in Section 3. Section 4, then, presents the results of the complex network analysis of SAAN, after which the paper is concluded with an overview of our major findings, the limitations of our approach, and some avenues for further research.

2. Literature review

2.1. A growing air transport market in the context of regional integration

Southeast Asian countries have very different experiences with regional integration. It is well documented that regional economic integration in East Asia - including a large part of its Southeast Asian component - has been preceded by fast-paced industrial development in Japan and the emergence of newly industrializing countries (NICs) - South Korea, Taiwan, Hong Kong, and Singapore - since the mid-1960s (Yap, 2014). Consecutive waves of relocating labour-intensive industries then cascaded down to next-tier NICs - Indonesia, Malaysia, Thailand - and later to the Philippines after it introduced a transition towards more liberal economic policies from the early 1980s onwards (Coclanis and Doshi, 2000). Meanwhile, the three Indochinese economies (i.e. Vietnam, Laos and Cambodia) were trapped in conflicts and isolated from the SEA regional market for more than a decade after 1975. They subsequently embarked on a trajectory of regional economic integration through a fundamental shift in development strategy from a centrally planned economy to a market economy since the late 1980s, as exemplified by Vietnam's *Doi Moi* reforms (Hill and Menon, 2012). By 1993, CLMV countries had all embraced market mechanisms, emphasizing export promotion, welcoming foreign investment, and promoting tourism (Thant, 2012). The flows of trade and investment to these newcomers to regional integration led to the establishment of broader regional production networks. As a consequence, regional integration in SEA has been significantly accelerating since the early 1990s: Tanaka (2009) demonstrates that the intraregional trade has almost doubled over the past two decades and now constitutes a quarter of the region's total trade.

Enhanced intercity airline connectivity has been part and parcel of SEA's evolution towards greater regional integration and the development of a single economic market. Since the Association of Southeast Asian Nations (ASEAN) was founded in 1967, it has facilitated both improved regional economic integration and air transport connectivity, seeing both as being fundamentally intertwined. A key step was the agreement on an ASEAN Free Trade Area (AFTA) in 1992. The AFTA framework carried a commitment to further enhance regional cooperation by providing safe, efficient and innovative transportation and communications infrastructure networks. This boosted a series of subregional air liberalization initiatives, such as a joint agreement by Indonesia, Malaysia, and Thailand in 1994 to promote the development of air transport in ASEAN's Northern Growth Triangle. The agreement was later broadened to include the Philippines and Brunei, and was supplemented with a similar CLMV cooperation in 1998, which liberalized air transport between the four countries. Another important step was the 2003 agreement to building the AEC by 2015 in order to move SEA towards an integrated and globally competitive single market and production base. Under this umbrella, Southeast Asian governments have been engaged in concerted efforts to work out an open skies policy similar to the one realized in the EU, namely the ASAM. Against this background, the airline industry in SEA has been evolving from an assortment of individual and highly-protected companies into an increasingly integrated and liberalized system of regional business organizations.

According to data from the Official Airline Guide (OAG) database (http://analytics.oag.com/), SEA has witnessed substantial expansion in its regional air transport network over the past three decades. More than 60 new airports have been constructed and/or come into operation during the 1979–2012 period, while the number of direct intra-SEA air connections has nearly doubled from 330 to 602. In line with booming regional economic output and surpassing overall population growth, the total volume of scheduled air passenger traffic within SEA has increased dramatically from 23.9 million in 1979 to 234.9 million in 2012 (Fig. 1).

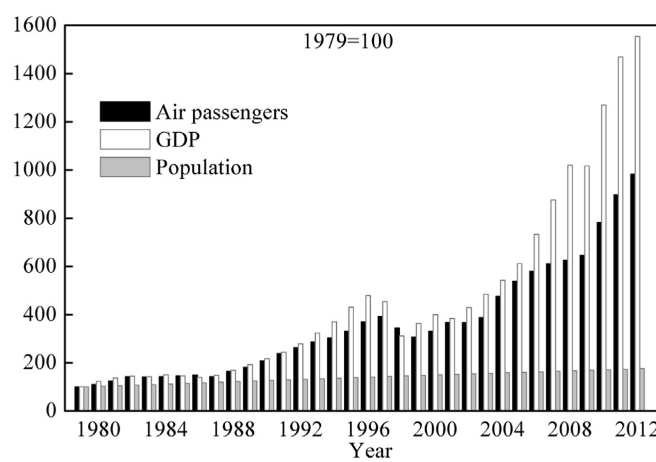

Fig. 1. Growth of scheduled air passenger traffic, GDP and population of Southeast Asia, 1979–2012 (Scheduled air passenger traffic from 1979 to 2012 was compiled from the OAG database. GDP and population data for each of the eleven Southeast Asian countries were gathered from World Bank (https://data.worldbank.org/). Since the World Bank GDP data of CLMV countries were incomplete, they were crosschecked and supplemented by data from http://ivanstat.com. Data from both sources were counted in current U.S. dollars (at 2015 prices). There was no GDP information for East Timor before 1999, since it was part of Indonesia. This confirmed the necessity to include it in our longitudinal study to keep geographic and statistical consistency although it has not become a formal ASEAN member yet.). The data in 1979 were standardized as 100 and those in other years were scaled according to this benchmark.

These evolutions have drawn considerable attention from air transport geographers. One the one hand, transport geographers have been interested in the positionality of cities and the (geo)spatial patterns of linkages between them, as well as their complex associations with economy, tourism, state policies, etc. For example, Bowen (2000) examined the changes in nodal accessibility of Southeast Asian hubs during 1979–1997 and assessed how different state policies and strategies shaped the development of air transport networks. Rimmer (2000) analyzed the impacts of the Asian Crisis on the geography of ex/intra-SEA air traffic with particular attention to changes in city-pair routes. On the other hand, researchers have discussed the mixed blessings of deregulation/privatization trends and emerging open skies policies for the Southeast Asian aviation market with regard to airports/cities, carriers, and air routes (Forsyth et al., 2006; Hooper, 2005).

Taken together, these studies offer insight into the changing geographies of the SAAN in light of a series of socio-economic and politico-institutional dynamics in SEA. However, there is relatively limited insight into the structural changes of and in the network. An exception is O'Connor's (1995) elaboration of a four-stage model of the historical development of the SAAN. He states that the network begins with "major destinations and trunk route stops" due to colonialism; then bypassing some places to exhibit "new intermediate conditions" with the development of national/regional economies and the advancement of aircraft technology; then entering into the "international hub development and proximity" stage by concentration of feeder connections from small cities; followed by the final "principal axis shift" from the traditional west-east to a north-south orientation with an increased vitality of southern cities. Complementing O'Connor's classical spatial analysis, here we attempt to uncover the evolution of overall SAAN structures through complex network analysis, which could provide insights into the network topological structure and multilayered geographical structure.

2.2. Complex network analysis on air transport networks

Situated at the intersection of graph theory and statistical mechanics, complex network theory offers an array of useful tools to analyze network structures, dynamics and their underlying mechanisms (Ducruet and Lugo, 2013). This has resulted in a bourgeoning literature (re)examining various transportation networks, such as urban public transport (Cats, 2017), road (Xie and Levinson, 2009), railway (Wang et al., 2009), maritime (Ducruet and Notteboom, 2012), and airline networks (Lin, 2012).

Air transport networks, in which airports/cities represent nodes and flights represent edges connecting these nodes can be conceptualized as either binary or weighted networks. Obviously, air transport networks are neither simply random or regular. Therefore, a complex network analysis of their structures starts with topological characterization and pattern recognition, with particular reference to scale-free and small-world networks. A scale-free network is characterized by a power-law distribution of nodal degree (i.e., a node's number of adjacent neighbors), showing that a few large degree nodes dominate a large number of less connected nodes (Barabási and Albert, 1999). In comparison, a small-world network has a larger density of edges because of a shorter average/characteristic path length (i.e., the average number of edges in the shortest path between two nodes) and higher transitivity (i.e., probability for a node to have its neighbors interconnected) than a random network of the same size (Watts and Strogatz, 1998).

These concepts and models have been tested in a number of air transportation networks, including the entire world (Guimera et al., 2005), the EU (Lordan et al., 2014), the United States (US; Xu and Harriss, 2008), China (Wang et al., 2011), India (Bagler, 2008), and Italy (Guida and Maria, 2007). In general, these studies examine overall network structures as well as indices for individual nodes, after which the implications of the network analysis results are explored. The presence of scale-free properties is related to the existing literature on hub-and-spoke configurations (O'Kelly, 1998). Nonetheless, the degree distribution can be very distinct in different air transportation systems, as can the shape of the distribution ranging from (stretched) exponential to power law (with or without cutoff), to two-regime/double power law (cf. Reed, 2003). Against the backdrop of this diversity, Paleari et al. (2010) compared the structure of air transport networks in the US, EU and China. The results showed that all three airport systems are characterized by a double Pareto-law (i.e. a two-regime power law) degree distribution, but with the distribution declining more rapidly in the EU. Overall, 'small-worldiness' is more universal in non-planar networks (i.e. networks that allow links to cross without creating a node at the intersection) due to the existence of communities, a set of nodes sharing denser connections with each other than with the rest of the network.

It can be noted that the above-discussed analyses are cross-sectional. However, with the growing availability of coherent longitudinal datasets, several studies focus on the historical evolution of air transport networks. For instance, Wandelt and Sun's (2015) analysis of international air transport networks from 2002 to 2013 indicated that the scale-free and small-world properties were stable and the network shifted towards symmetric, transitive closure due to the increasing interconnection between each country's neighbors. Burghouwt and Hakfoort (2001) explored the evolution of the European aviation network during 1990–1998, and demonstrated the development of hub-and-spoke structures notwithstanding there being no evidence for concentration of intra-European traffic on the primary hubs. Lin and Ban (2014) studied both topological and spatial characteristics of the US airline network during 1990–2010, finding stability in topology and an increasing importance of distance in the development of new routes. That is, more and more short- and medium-length (< 700 km) routes have been created, and passengers increasingly need one or more transfers to realize a long-distance connection due to network structure optimization and integration. The evolution of the Chinese air transport network since 1930 was examined in Wang et al. (2014), indicating a significant improvement of connectivity and a gradual expansion of a core network along with the development of China's economy (cf. Liu et al., 2016). Rocha (2009) discovered a relatively high and stable clustering coefficient and a slightly declining average path length for the Brazilian airport network, as well as a shrinkage of network routes in spite of a more than doubling of air traffic between 1995 and 2006.

Apart from conventional topological analysis in cross-sectional and longitudinal studies alike, multilayer/multilevel analysis has become prevalent within the framework of complex network theory (Tsiotas and Polyzos, 2017). Recent major contributions in this light are Verma et al. (2014), Du et al. (2016) and Lordan and Sallan (2017). These authors employ the *k*-core decomposition method to uncover the multilevel structure of the worldwide, Chinese, and European air transport networks, respectively. *K*-core decomposition is a technique to hierarchically identify particular subsets of a complex network, called *k*-cores, in which the degree of every node is larger than or equal to *k*. Each subset is obtained by recursively removing all nodes with degree smaller than a certain threshold *k* (Ducruet and Zaidi, 2012). This approach progressively disentangles the complexity of airline networks, thus providing insight into the different layers unevenly contributing to the configuration of the network. Because, as we will see, the SAAN exhibits both high complexity and spatial inequality, such a multilayer analysis is of the utmost interest to help grasping the geographies of the network.

This literature review leads us to three major observations in the context of this paper. First, air transport networks have been widely analyzed in terms of the statistical properties of the network structure. However, these studies have primarily focused on the US, European countries, China, and India: the SAAN thus appears under-researched from this perspective. Second, most studies examine the static state of the network in a single year through the lens of complex network theory: longitudinal analysis could help revealing underlying geographic, political and economic factors in the structuration of the network. Third, multilayer/multilevel analysis has evolved into a prominent approach to discover hidden information and extract hierarchical structures from complex networks. However, this approach has not yet been widely adopted in research on air transport networks. Against this backdrop, this paper examines the evolving structure of the SAAN from 1979 to 2012 by means of multilevel complex network analysis, and discusses these with key social and economic changes in the region. In the next section, we will elaborate on the methodology and data used in this study.

3. Data and methods

3.1. Working hypotheses

To better organize our empirical analyses, we make the following working hypotheses based on the existing literature: (1) The SAAN network is characterized by a core-periphery structure. In other words, there are a few well-connected cities (hubs) with a large number of air passenger routes while the majority of cities (spokes) only have a limited number of connections (cf. Bowen, 2000). (2) The SAAN network becomes more connected over time meanwhile the dominance of hub cities become more pronounced; and (3) Capital cities and economically more important cities remain better connected over time. As our analysis is exploratory, we will use these working hypotheses as the starting point for our examination.

3.2. Data

All our data refer to nonstop flights and air passengers scheduled between any pair of airports within Southeast Asia (Fig. 2), as detailed in the aforementioned OAG database (see Derudder and Witlox (2008) for a discussion of data limitations). Our empirical study was conducted between 1979 and 2012 on a yearly basis: 1979 was taken as a starting point as it can be seen as a benchmark in that it marks the onset of ASEAN air transport liberalization, while 2012 was determined by data availability.

3.3. Complex network methods

3.3.1. Network representation

The SAAN takes the form of a symmetric adjacency matrix A wherein $a_{ij} = 1$ if there are scheduled flights between airport city i and city j in the studied year and $a_{ij} = 0$ of otherwise. Each airport city represents a single node except for a number of aggregations related with the presence of multi-airport cities (cf. Derudder et al., 2010), i.e. a combination of Suvarnabhumi (BKK) and Don Mueang (DMK) into Bangkok, Kuala Lumpur International (KUL) and Sultan Abdul Azziz Shah (SZB) into Kalua Lumpur, Soekarno-Hatta (CGK) and Halim Perdana Kusuma (HLP) into Jakarta, and Changi (SIN) and Seletar (XSP) into Singapore. The number of nodes in the SAAN ranges from 177 in 1979 to 237 in 2012. Given our focus on connections/passengers within SEA, we use the term ‘domestic’ or ‘internal’ to refer to connections/passengers between cities in the same country while ‘international’ or ‘external’ is used to refer to connections/passengers between cities in different SEA countries.

3.3.2. Network structure measures

The starting point for evaluating network structures is to introduce a set of fundamental network metrics, such as degree, degree distribution, degree-degree correlation, characteristic path length and average clustering coefficient. Degree is the most basic index to measure the centrality of nodes in a network, while the degree distribution helps exploring the underlying processes by which the network has come into existence. Degree-degree correlation reflects a node's connection preference and reveals the mixing pattern of an observed network. Characteristic path length is a global property that is essential to the topology and communication efficiency of networks, while the average clustering coefficient allows quantifying the degree of clustering of a network. Below we formally specify each of these measures.

(1) Degree and degree distribution

The degree k_i of node i is defined as the number of nodes it is

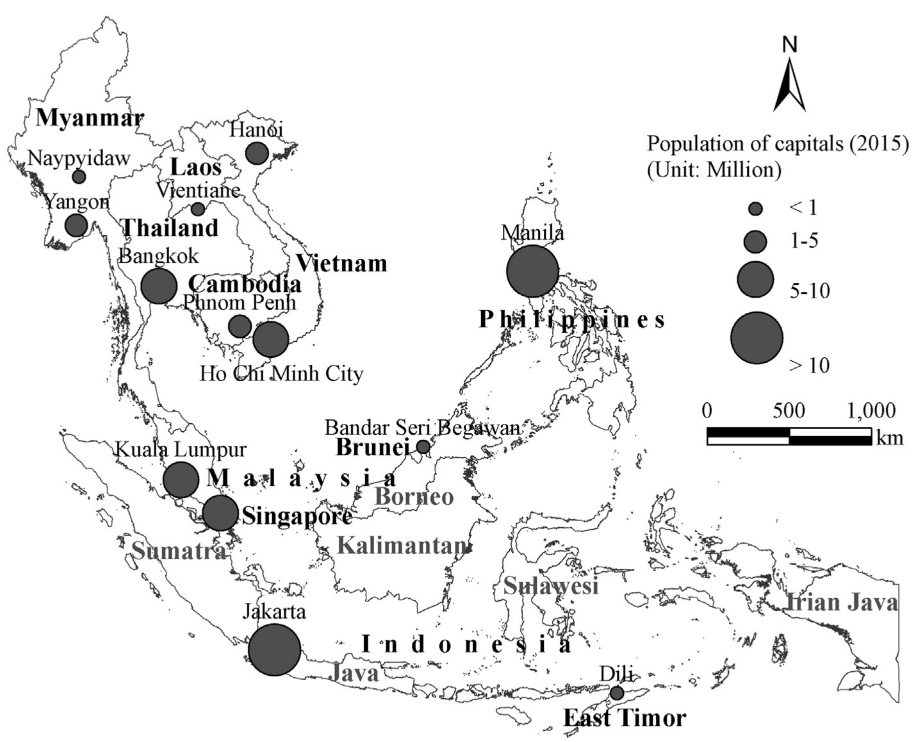

Fig. 2. The SEA study area. (The population of capital cities in 2015 was derived from https://aseanup.com/infographic-top-cities-urbanization-asean/. Yangon and Ho Chi Minh City were dotted in the map since they are former capitals of Myanmar and Vietnam, respectively.)

directly connected to, and is given by:

$$k_i = \sum_{j \in V(i)} a_{ij} \quad (1)$$

where $V(i)$ denotes the neighbor set of node i.

For a scale-free network which is generated by a preferential attachment rule, the degree distribution $p(k)$ follows a power law, given by:

$$P(k) \sim k^{-\gamma} \quad (2)$$

where γ is the fitted power-law exponent.

We compute the cumulative degree distribution $P(>k)$, as it paints a more accurate picture of the shape of the distribution in relatively small and noisy datasets (Lordan et al., 2014). The cumulative degree distribution $P(>k)$ expresses the probability of nodes with degree equal to or greater than k and is given by:

$$P(>k) = \sum_{k'=k}^{\infty} p(k') \quad (3)$$

whose scaling exponent γ_{cum} is related to that of $P(k)$ by $\gamma = \gamma_{cum} + 1$.

(2) Degree-degree correlation

This refers to the correlation between degree k and the average degree of their neighbors $\overline{K(k)}$:

$$K(i) = \frac{1}{k_i} \sum_{j \in V(i)} k_j \quad (4)$$

where $K(i)$ is the average degree of the neighbors of node i. For $N(k)$ nodes with degree k, $\overline{K(k)}$ is defined as:

$$\overline{K(k)} = \frac{1}{N(k)} \sum_{k_i = k} K(i) \quad (5)$$

A positive coefficient indicates a correlation between nodes of similar degree, termed 'assortativity'. A negative value indicates relationships between nodes of different degree, termed as 'dis-assortativity' (Newman, 2003).

(3) Characteristic path length

The characteristic path length L is defined as the average number of edges along the shortest paths for all possible node-pairs in the network:

$$L = \frac{1}{N(N-1)} \sum_{i,j=1}^{N} d_{ij} \ (i \neq j) \quad (6)$$

where d_{ij} is the number of edges for the shortest path from node i to j.

(4) Average clustering coefficient

The clustering coefficient C_i is defined as the probability that two nodes are connected to each other given that both of them are connected to node i, written as:

$$C_i = \frac{2E_i}{k_i(k_i - 1)} \quad (7)$$

where E_i indicates the actual number of edges between the neighbors of node i. The average clustering coefficient C is the mean value of Ci of all N nodes in the network:

$$C = \frac{1}{N} \sum_{i=1}^{N} C_i \quad (8)$$

The characteristic path length and average clustering coefficient are two basic indices that allow testing whether a network exhibits small-world properties: a network in which most nodes are not neighbors of one another, but in which the neighbors of any given node are likely to be neighbors of each other and most nodes can be reached from every other node by a small number of connections. If a network has a higher C and a shorter L than those in an identical-size random network, it suggests the presence of small-worldiness.

3.3.3. K-core decomposition

In addition to the metrics discussed in Section 3.3.2, we will also explore the SAAN's multilayered structure by drawing on the k-core decomposition method. A network can theoretically be decomposed into 1, 2, 3, …, k_{max} layers. However, it is not very informative to present all layers separately. Rather, and as highlighted in Verma et al. (2014), nodes in the air transport network can be categorized into three distinct layers: core, bridge and periphery. The core layer contains the nodes belonging to the k_{max}-core while the periphery layer includes the nodes in the 1-core; the remainder of the network forms the bridge layer. We employ this classification to decompose the SAAN into a hierarchical core-bridge-periphery structure.

4. Results

4.1. Statistical properties of the SAAN topological structure

We begin our analysis by looking at the network architecture in 2012 and then tracing its changes over the period 1979–2012. Table 1 summarizes the basic network metrics of the SAAN, and compares these results to those for other regions as reported in the literature.

4.1.1. Scale-free properties

As can be seen in Fig. 3, the SAAN's $P(>k)$ fits a power-law function with a scaling exponent of $\gamma_{cum} = 1.42$ in 2012. Therefore, the corresponding exponent γ for $P(k)$ is $1 + 1.42 = 2.42$. Given that this is in the range of $2 < \gamma < 3$, this characterizes the SAAN as a scale-free network as previously observed for India and Austria as well as, to a lesser extent, for the global level and the US, the EU and Italy (cf. Table 1). This confirms our first hypothesis regarding the dominance of a few well-connected cities (hubs) in SEA with a large number of air passenger routes (cf. Bowen, 2000). The shape of the distribution

Table 1
Summary statistics of the SAAN in 2012 and its counterparts (V: number of nodes; E: number of edges; P(> k): cumulative degree distribution; L: characteristic path length; C: average clustering coefficient).

Scale	Network	Reference	V	E	P(> k)	L	C
Macro-regional	Southeast Asia		237	602	Power law	3.12	0.21
Global	Worldwide	Guimera et al., 2005	3663	27,051	Truncated power law	4.40	0.62
Macro-regional	EU	Lordan et al., 2014	661	8104	Double Pareto law	2.71	0.55
National	US	Xu and Harriss, 2008	272	6566	Truncated power law	1.90	0.73
	China	Wang et al., 2011	144	1018	Exponential	2.23	0.69
	India	Bagler, 2008	79	228	Power law	2.26	0.66
	Italy	Guida and Maria, 2007	42	310	Double Pareto law	1.98	0.10
	Austria	Han et al., 2007	136	1296	Power law	2.38	0.21
	Greece	Tsiotas and Polyzos, 2017	41	154	Exponential	2.09	0.42
	Brazil	Rocha, 2009	142	2601	Streched exponential	2.34	0.63

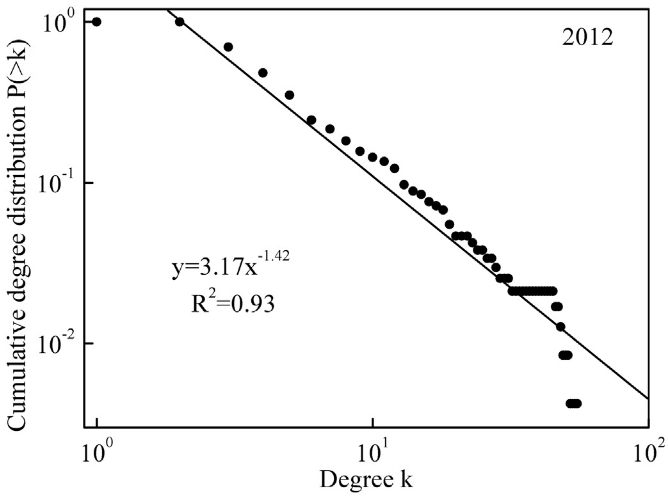

Fig. 3. Cumulative degree distribution of the SAAN plotted using a double-logarithmic scale, 2012.

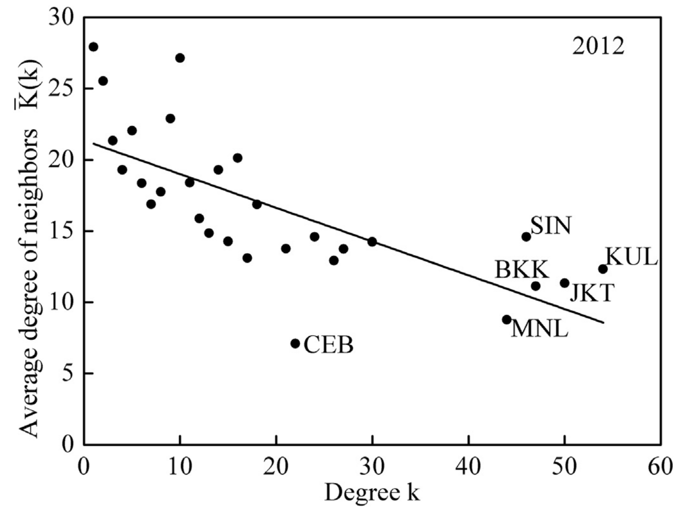

Fig. 5. Degree-degree correlation for the SAAN, 2012 (SIN: Singapore; KUL: Kuala Lumpur; BKK: Bangkok; JKT: Jakarta; MNL: Manila; CEB: Cebu).

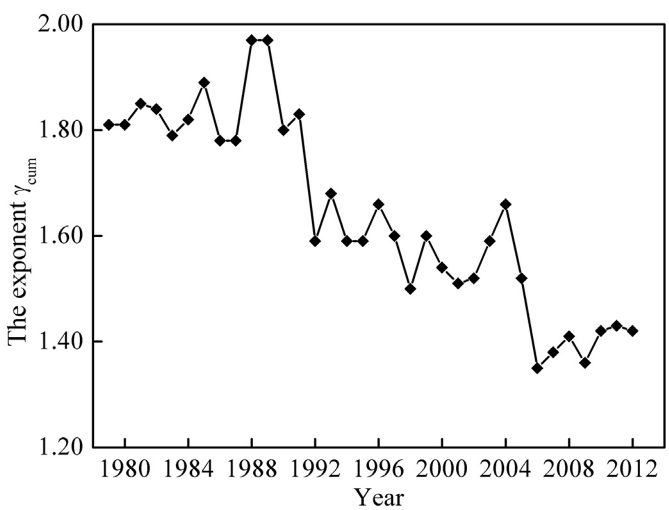

Fig. 4. Fitted exponents for the power-law distribution, 1979–2012.

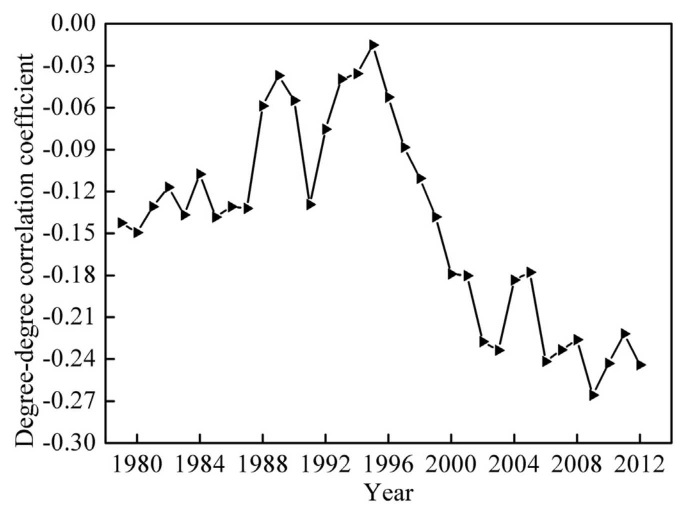

Fig. 6. Disassortativity coefficients for the SAAN, 1979–2012.

remains roughly similar between 1979 and 2012, implying that even with strong rewiring at the micro level (see Section 4.2), the overall characteristics of the network have remained roughly the same. Nevertheless, the slope of the degree distribution generally decreased (Fig. 4), meaning that there are relatively more cities with a large degree. This is above all the result of the recent emergence of Indochina and the continued expansion of Thai, Malaysian and Indonesian cities as indicated in O'Connor (1995). The minor deviations in some of the years may be attributed to the sensitivity of air transport to sudden events, such as the outbreak of economic crisis in 1997 and the severe acute respiratory syndrome (SARS) in 2003 (Bowen and Laroe, 2006; Rimmer, 2000).

4.1.2. Disassortative mixing

Fig. 5 demonstrates the presence of a negative correlation between a city's degree and the average degree of its neighboring cities for the SAAN in 2012. This points to a disassortative mixing pattern in which high-degree cities such as Singapore, Kuala Lumpur, Bangkok, Jakarta and Manila on average have relatively low-degree neighbors. Cebu is an outlier here in that, as a medium-sized city, its average neighbor degree is less than half of the expected value. This can be ascribed to a ‘shadow effect’ (cf. O'Connor, 1995) of its major hub, Manila, which confines Cebu's connections to domestic small cities instead of major cities in other countries. In contrast, Singapore neighbors' average degree is higher than expected. This suggests that it is directly connected to many primate cities and secondary cities in other countries, compensating for the relatively smaller number of connections with low-degree cities.

Fig. 6 shows disassortativity to be slowly declining from −0.14 in 1979 to −0.01 in 1995 (pointing to an almost neutral mixing pattern). Since 1995, however, disassortativity has again roughly intensified, although the mixing pattern in 2012 is still not very strong. The two stages identified here are the joint result of a changing diversity of pairs of connected cities and the partial hierarchical structure (Ru and Xu, 2005). The growing importance of air transport and the integration of more remote local cities into the national and regional development process implies that small cities increasingly rely on hub-and-spoke configurations to attain better accessibility in SEA (Lin, 2012).

4.1.3. Small-world properties

Fig. 7. presents the characteristic path length and average clustering coefficient of the SAAN and a comparable network (i.e. with the same number of edges and nodes) with a random distribution. In the case of the SAAN, L is very close to that of a random network with a turning point in 1996 when the random network's L starts surpassing that of the SAAN. The clustering coefficient is nevertheless continuously significantly higher than that of a comparable random network. Hence, the SAAN exhibits small-world properties from 1996 onwards. One possible explanation for this is that major Low-Cost Carriers (LCCs) came into

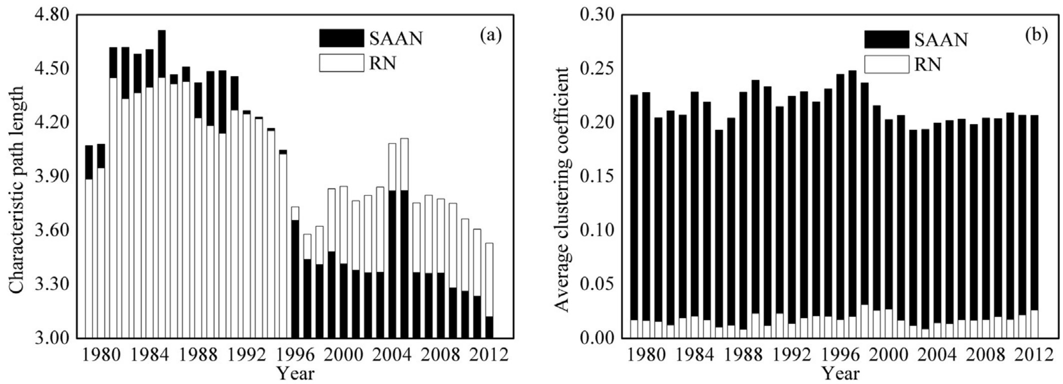

Fig. 7. Characteristic path length (a) and average clustering coefficient (b) of the SAAN compared to those of the random network (RN) in the same size, 1979–2012.

focus after 1996, such as Cebu Pacific, Lion Air, AirAsia, Jetstar Asia (Zhang et al., 2008), which has greatly densified the overall intercity air transport network and improved the accessibility of many secondary cities in this region.

From 1979 to 2012, *L* decreased from 4.07 to 3.12, conforming to an average decline of one step for cities to reach other cities in the SAAN. *C* remained stable around 0.2, which suggests a trade-off between efficiency and economic considerations (Xie et al., 2015). Compared with other regions in Table 1, the SAAN has a large characteristic path length of 3.12 whereas the worldwide network has a larger value at 4.4. It can of course be hypothesized that *L* will increase with the scale of the networks because distance and border effects still matter in air transport networks (Matsumoto, 2007). As a result, the level of *L* at the national level is usually smaller than that at the macro-regional level, which is in turn also smaller than that at the global level.

However, the EU network does possess a shorter characteristic path length of 2.71 and a larger average clustering coefficient of 0.55 compared to the SAAN, implying that SEA, as a single bloc, remains at a less-developed stage in air transportation with much room to improve the efficiency of the connectivity structure of its air transport network (Wang et al., 2011): in an increasingly liberalized economic environment, the SAAN is still far from an integrated and mature market. Compared to the extensive multilateral agreements and low-cost connections across countries as in the EU (Dobruszkes, 2006), current liberalizing processes in SEA still largely rely on bilateral air service agreements in which a substantial number of routes are exposed to government regulations (Hanaoka et al., 2014).

4.2. Spatiotemporal variations of the SAAN multilayered structure

In this section, we present a more detailed morphology of the SAAN's multilayered structure and discuss its changes by taking multiple snapshots at different time points. Fig. 8 displays the hierarchical core-bridge-periphery structure of the SAAN in 1979, 1996, 2012, respectively, and Table 2 reports the number of cities, connections and air passengers within and between layers.

The SAAN has changed markedly by growing from 177 cities linked through 330 connections in 1979 to 237 cities linked through 602 connections in 2012. At the same time, the number of air passengers soared to 234.69 million from a relative small base of 23.89 million. Prior to the outbreak of the 1997 financial crisis, the SAAN enjoyed faster growth in the number of cities, connections and passengers by 33.33%, 65.45% and 270.07%, respectively, than those in the subsequent period (0.42%, 10.26% and 165.50%, respectively). In terms of the multilayered structure, the three layers (i.e. core, bridge, and periphery) exhibit heterogeneous patterns over space and time, in which several major changes can be identified.

First, there is a minor drop in the number of cities in the core layer, but at the same time there has been a substantial gain in the intensity of the connections. As can be seen in Fig. 8, the core layer has evolved into a well-developed and tightly connected backbone with the gravitational center moving towards the northern part of SEA. This tendency is in line with O'Connor (1995) "principal axis shift". In 1979, the 23 core cities were capital cities of economically developed countries alongside a number of large cities in archipelagic countries (i.e. Indonesia, Philippines, Malaysia). The core layer had 68 connections connecting 13.85 million passengers. However, the number of core cities in 1996 was almost halved, while the connections between them also decreased to 45 whereas the number of air passengers more than doubled. Cities that remained in the core layer were capital cities of economically developed countries, provincial capitals of East Malay (Kuching and Kota Kinabalu), as well as the second largest city (Surabaya), the most well-developed tourist destination (Denpasar) and the busy domestic hub of Makassar in Indonesia. After a further 17 years, the core layer witnessed a moderate growth in size (18 cities and 87 connections) and a drastic rise in the number of passengers (85.13 million). The layer includes all capital cities of the SEA region except for Vientiane, a number of critical secondary cities and international gateways (i.e. Penang, Surabaya, Medan), as well as the region's important tourist destinations (i.e. Phuket, Siem Reap and Denpasar).

Second, the bridge layer has gone through a mixed growth pattern, above all exhibiting high volatility during 1979–2012. Initially, the connections between bridge cities were relatively sparse. Air passenger flows were concentrated in the remote parts of East Indonesia around Makassar on the one hand, and a Northwest Burmese group around Yangon on the other hand. The layer mushroomed in 1996 with connections and traffic more than doubling and quadrupling respectively. This is largely due to the emergence of Vietnamese cities as well as a number of Indonesian and Philippine cities that were downgraded from the core layer. In 2012, the number of cities and connections respectively shrank by 12.5% and 32.2%. It is noteworthy that Chiang Mai and Da Nang became prominent bridge cities in the Greater-Mekong sub-region in the face of the rise of Ho Chi Minh City, Hanoi and Yangon to the core layer. Besides, Makassar reappeared in this layer after 1996's temporary upgrade into a core city, with the connections between the divided parts of Malaysia being much denser in 2012.

Third, the periphery layer has a consistent low significance in the SAAN with a gradually rising number of cities located at the margins of their national systems and rarely being inter-connected. However, these cities are increasingly connected to cities in core and bridge layers. This phenomenon has also been observed in the spatial organization of freight flows between French urban areas, featuring only a few exchanges between small urban areas, but more with other levels in the urban hierarchy (Guerrero and Proulhac, 2014). In a similar vein, the connections between bridge and core layers ascended drastically from 92 to 251, with a parallel growth in air traffic from 5.88 to 114.29 million. This of course leads to the disassortative mixing of degrees discussed in Section 4.1.2.

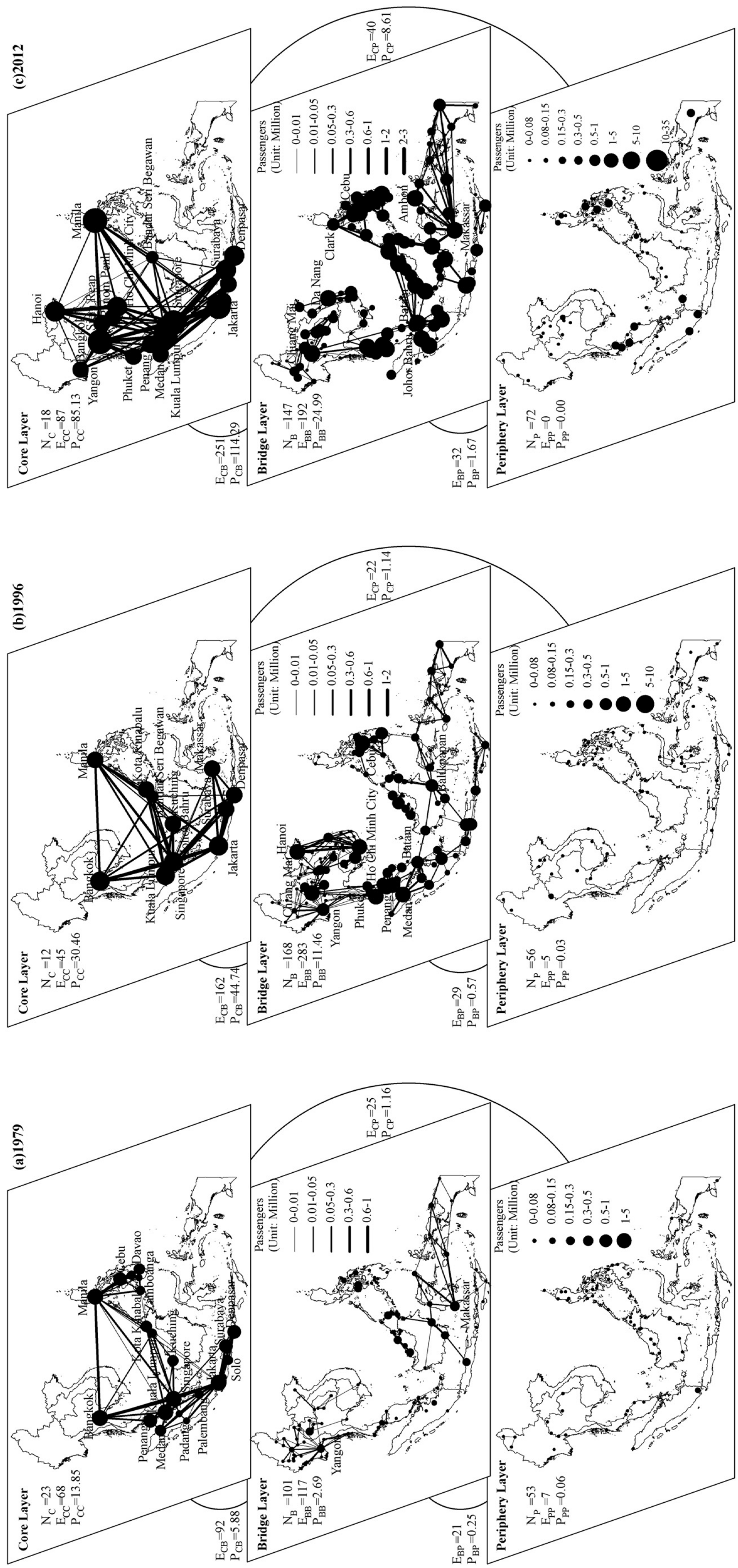

Fig. 8. The three layers of the SAAN in 1979, 1996 and 2012. E denotes the number of connections within (Ecc, Ebb, and Epp) or between (Ecb, Ecp, and Ebc) layers; P denotes the passengers within (Pcc, Pbb, and Ppp) or between (Pcb, Pcp, and Pbc) layers; and N denotes the number of nodes in each layer (Nc, Nb, and Np).

Table 2
Number of cities, connections and air passengers within and between layers in the SAAN.

Type	Cities			Connections			Passengers (million)		
	1979	1996	2012	1979	1996	2012	1979	1996	2012
Core	23	12	18	68	45	87	13.85	30.46	85.13
Core-bridge	–	–	–	92	162	251	5.88	44.74	114.29
Core-periphery	–	–	–	25	22	40	1.16	1.14	8.61
Bridge	101	168	147	117	283	192	2.69	11.46	24.99
Bridge-periphery	–	–	–	21	29	32	0.25	0.57	1.67
Periphery	53	56	72	7	5	0	0.06	0.03	0.00
Sum	177	236	237	330	546	602	23.89	88.39	234.69

The dynamics of the multilayered structure in the SAAN can easily be associated with the geographic peculiarities of, and socio-economic and politico-institutional changes in SEA (Liu et al., 2013, 2017). First and foremost, the region's fragmented geographical nature continues shaping the spatial and topological patterns. For instance, especially for remote areas with small population and economic output, Makassar acts as a local hub in Indonesia to handle frequent air links from densely-populated Java to Sulawesi and Irian Java. Given that the Malaysian communities on Borneo are both relatively less developed and isolated from the Malay Peninsula, intense air connections are established to numerous cities in East Malaysia (often through Kuching and Kota Kinabalu). This geographical dispersion of archipelagic countries has placed an unusual dependence on air services as a unifying force to keep the national development project on track (Kissling, 1989).

Furthermore, the evolving multilayered geography of the SAAN is heavily influenced by underlying disparities in national development and regional integration as reviewed in Section 2.1. One the one hand, the early NICs, being export-oriented, started to integrate into the global economy, thus reinforcing the significance of their respective international hubs by synergies of soft (e.g. information, telecommunication) and hard (e.g. airport, port, rail and road) infrastructures (Airriess, 2001; Rimmer, 1999; Robinson, 2006). For instance, with the development of high tech and value-added manufacturing and business services, Singapore has become one of the major investors in other Southeast Asian countries. Therefore, it has geared its soft (e.g. management and amenities) and hard (e.g. new airport terminals) infrastructures (Phang, 2003) towards attracting layover passengers during long-haul inter-continental flights. On the other hand, the lagging CLMV got involved into the regional production network by economic reforms from the late 1980s and joined ASEAN later on (Vietnam in 1995, Laos and Myanmar in 1997, and Cambodia in 1999). In Vietnam, Ho Chi Minh City, Hanoi and Da Nang were designated as three development poles and have enjoyed rapid economic growth from a small base, which spurs investment in air transport connections to external economies. In addition, the CLMV subregional cooperation in air transport since 1998 contributes to an improved competitiveness and gradual participation in the international air transport market (Hien, 2003), ultimately bolstering the capital cities of CLMV in the core layer in 2012. An equally important contributor has been the growing volumes in tourism (Van De Vijver et al., 2014). This shift leads to mushrooming air connections to Siem Reap (the world heritage site of Angkor Wat), and Phuket and Denpasar (resort islands), all of which are also included in the core layer in 2012.

Finally, government policies played a vital role in the SAAN evolution (Bowen, 2000). Before the 1990s, air services were overwhelmingly state-regulated or even state-operated in SEA. National carriers played an instrumental role the processes of nation-building, serving to integrate various parts of a country on the one hand and reinforcing the positionality of the national capital cities on the other hand (Raguraman, 1997). Partly in order to cope with the rapid growth of air transport demand, most SEA countries started to permit the entry of private corporations into the aviation industry (Hooper, 2005), while flagship carriers shifted towards regional and international cooperation and competition. The gradual deregulation of domestic markets promoted joint-venture LCCs, such as Malaysia's AirAsia which is perceived to be a pan-ASEAN carrier (Zhang et al., 2008). The connections provided by these carriers greatly enhanced the nodal accessibility of most economically vibrant secondary cities and tourism destinations as pronounced in the core layers of 1996 and 2012.

The impact of air transport liberalization can also be detected from the presence of Johor Bahru and Clark in 2012 in the bridge layer with dense connections. The emergence of Johor Bahru in the SAAN can be ascribed to the ‘spillover effect’ of Singapore owing to geographic proximity (Ooi, 1995) as well as its potential to be the secondary airport of Singapore with convenient ground transportation between both places. A similar observation can be made for Clark, an airport city 80 km away from Manila, which is increasingly well connected by its attraction of connectivity from congested Manila airport (Hanaoka et al., 2014). In our empirical framework, we initially opted to aggregate these airports into ‘city nodes’, but these findings suggest that a more nuanced reading of connectivity in a city-regional context would have been warranted. This is, of course, in line with Addie's (2014) coining of the concept of aero-regionalism to enhance and reshape our understanding of the relations between aviation infrastructures and their surrounding regional spaces.

5. Conclusions

In this paper, we examined the evolving SAAN using tools derived from complex network theory. Both topological features and spatial patterns were taken into account. Starting from the longstanding focus of air transport geographers on changing positions of cities and connections in air transport networks, we have aimed to contribute to the literature by exploring the topological and multilayered structures of the SAAN, and tracing its evolution over the period 1979–2012.

The topological structure of the SAAN has exhibited relative stability over the past 34 years. It follows a power-law degree distribution, suggesting scale-free properties as previously observed for air transport networks in India, Austria and, to a lesser extent, in the global, US, EU and Italian networks. The slope of the degree distribution generally decreased, indicating more cities now having a large degree. This is largely due to the emerging hubs in CLMV countries. Meanwhile, the SAAN has been characterized by small-world properties since 1996 when its characteristic path length and average clustering coefficient were both above values of a comparable random network. Furthermore, the SAAN exhibits an intensified disassortativity, showing an increasing dependence of small cities on a hub-and-spoke configuration to access the entire network. However, compared to its EU macro-regional counterpart, the SAAN is far from mature and integrated.

The multilayered structure of the SAAN has changed over time and space, which can be traced back to a range of socio-economic and politico-institutional dynamics. The tourism boom has resulted in the entry of Phuket, Siem Reap and Denpasar into the core layer. And because of the more recent economic development of CLMV, the core layer is now shifting towards the northern part of SEA. Our analysis shows a prominent increase in connections and traffic between the core and other layers. Although more remote cities are integrated into the SAAN, connections between peripheral cities remain almost non-existent, which again suggests an increasing dependence of small cities on hub-and-spoke configuration to access the network.

There are, of course, a number of limitations associated with our approach. Our binary (as opposed to a weighted) specification of connections implies that we have focused on the major topological features of the SAAN, but this may result in losing sight on some of the nuances engendered in the edges being unevenly weighted. In addition, our study sheds light on the evolving structure of the SAAN from the perspective of air transport capacity/supply; it would also be interesting to conduct empirical studies from a demand dimension. Our analysis also has its data limitations. First, the network we analyzed is an aggregated one that does not differentiate between types of carriers (i.e. Full Service Carrier and LCCs) and airline companies (e.g. Tiger Airways, AirAsia, Jetstar). Second, the rise and fall of cities in these networks may mesh with changes in other modes of transportation, such as port and railway development, which cannot be identified in our study. With more refined and multiplex data, an improvement in these aspects would provide a more accurate understanding of the structural evolution in terms of development strategies and policies for cities and the air transport industry. And finally, our all-too-straightforward definition of what constitutes a node could be conceptually enriched by triangulating it with research on the diversity of the meaning of airport-cities and airport-regions as per Addie (2014) and Derudder et al. (2010).

Reference

Addie, J.-P.D., 2014. Flying high (in the competitive sky): conceptualizing the role of airports in global city-regions through “aero-regionalism”. Geoforum 55, 87–99.

Agnew, J., 1994. The territorial trap: the geographical assumptions of international relations theory. Rev. Int. Polit. Econ. 1, 53–80.

Airriess, C., 2001. Regional production, information–communication technology, and the developmental state: the rise of Singapore as a global container hub. Geoforum 32, 235–254.

ASEAN Secretariat, 2011. Master plan on ASEAN connectivity, Jakarta. Http://www.asean.org/storage/images/ASEAN_RTK_2014/4_Master_Plan_on_ASEAN_Connectivity.pdf.

ASEAN Secretariat, 2016. ASEAN Economic Community Chartbook 2016, Jakarta. Http://www.aseanstats.org/wp-content/uploads/2016/11/AEC-Chartbook-2016-1.pdf.

Bagler, G., 2008. Analysis of the airport network of India as a complex weighted network. Phys. A Stat. Mech. Appl. 387, 2972–2980.

Barabási, A.-L., Albert, R., 1999. Emergence of scaling in random networks. Science 286, 509–512.

Bowen, J., 2000. Airline hubs in Southeast Asia: national economic development and nodal accessibility. J. Transp. Geogr. 8, 25–41.

Bowen, J.T., Laroe, C., 2006. Airline networks and the international diffusion of severe acute respiratory syndrome (SARS). Geogr. J. 172, 130–144.

Bunnell, T., 2013. City networks as alternative geographies of Southeast Asia. TRaNS 1, 27–43.

Burghouwt, G., Hakfoort, J., 2001. The evolution of the European aviation network, 1990-1998. J. Air Transp. Manag. 7, 311–318.

Cats, O., 2017. Topological evolution of a metropolitan rail transport network: the case of Stockholm. J. Transp. Geogr. 62, 172–183.

Coclanis, P.A., Doshi, T., 2000. Globalization in Southeast Asia. Ann. Am. Acad. Polit. Soc. Sci. 570, 49–64.

Derudder, B., Witlox, F., 2008. Mapping world city networks through airline flows: context, relevance, and problems. J. Transp. Geogr. 16, 305–312.

Derudder, B., Devriendt, L., Witlox, F., 2010. A spatial analysis of multiple airport cities. J. Transp. Geogr. 18, 345–353.

Dick, H., 2005. Southeast Asia as an open system:Geo-politics and economic geography. In: Kratoska, P.H., Raben, R., Nordholt, H.S (Eds.), Locating Southeast Asia. Geographies of knowledge and politics of space. Singapore University Press, Singapore, pp. 250–274.

Dobruszkes, F., 2006. An analysis of European low-cost airlines and their networks. J. Transp. Geogr. 14, 249–264.

Du, W.-B., Zhou, X.-L., Lordan, O., Wang, Z., Zhao, C., Zhu, Y.-B., 2016. Analysis of the Chinese airline network as multi-layer networks. Transp. Res. E 89, 108–116.

Ducruet, C., Lugo, I., 2013. Structure and dynamics of transportation networks: Models, methods and applications. In: Rodrigue, J.-P., Notteboom, T., Shaw, J. (Eds.), The SAGE Handbook of Transport Studies. SAGE, pp. 347–364.

Ducruet, C., Notteboom, T., 2012. The worldwide maritime network of container shipping: spatial structure and regional dynamics. Global Netw. 12, 395–423.

Ducruet, C., Zaidi, F., 2012. Maritime constellations: a complex network approach to shipping and ports. Marit. Policy Manag. 39, 151–168.

Forsyth, P., King, J., Lyn Rodolfo, C., 2006. Open skies in ASEAN. J. Air Transp. Manag. 12, 143–152.

Guerrero, D., Proulhac, L., 2014. Freight flows and urban hierarchy. Res. Transp. Bus. Manag. 11, 105–115.

Guida, M., Maria, F., 2007. Topology of the Italian airport network: a scale-free small-world network with a fractal structure? Chaos, Solitons Fractals 31, 527–536.

Guimera, R., Mossa, S., Turtschi, A., Amaral, L.A.N., 2005. The worldwide air transportation network: anomalous centrality, community structure, and cities' global roles. Proc. Natl. Acad. Sci. 102, 7794–7799.

Han, D.D., Qian, J.H., Liu, G.J., 2007. Network Topology of the Austrian Airline Flights. (arXiv:physics/0703193 (last accessed 15 Feb 2018)) , Accessed date: 15 February 2018.

Hanaoka, S., Takebayashi, M., Ishikura, T., Saraswati, B., 2014. Low-cost carriers versus full service carriers in ASEAN: the impact of liberalization policy on competition. J. Air Transp. Manag. 40, 96–105.

Hien, P.V., 2003. Sub-regional Cooperation on Air Transport among Cambodia, Lao PDR, Myanmar and Vietnam, Fifth Worldwide Air Transport Conference. International Civil Aviation Organization, Montreal. Https://www.icao.int/Meetings/ATConf5/Documents/PhanVuHien.pdf.

Hill, H., Menon, J., 2012. ASEAN economic integration: Driven by markets, bureaucrats, or both? In: Kreinin, M.E., Plummer, M.G. (Eds.), The Oxford Handbook of International Commercial Policy. Oxford University Press, Oxford, UK, pp. 357–386.

Hooper, P., 2005. The environment for Southeast Asia's new and evolving airlines. J. Air Transp. Manag. 11, 335–347.

Kissling, C., 1989. International tourism and civil aviation in the South Pacific: issues and innovations. GeoJournal 19, 309–315.

Kratoska, P.H., Raben, R., Nordholt, H.S., 2005. Locating southeast Asia. In: Kratoska, P.H., Raben, R., Nordholt, H.S. (Eds.), Locating Southeast Asia. Geographies of knowledge and politics of space. Singapore University Press, Singapore, pp. 1–19.

Lin, J., 2012. Network analysis of China's aviation system, statistical and spatial structure. J. Transp. Geogr. 22, 109–117.

Lin, J., Ban, Y., 2014. The evolving network structure of US airline system during 1990-2010. Phys. A Stat. Mech. Appl. 410, 302–312.

Liu, X., Derudder, B., García, C.G., 2013. Exploring the co-evolution of the geographies of air transport aviation and corporate networks. J. Transp. Geogr. 30, 26–36.

Liu, X., Derudder, B., Wu, K., 2016. Measuring polycentric urban development in China: an intercity transportation network perspective. Reg. Stud. 50, 1302–1315.

Liu, X., Dai, L., Derudder, B., 2017. Spatial inequality in the southeast Asian intercity transport network. Geogr. Rev. 107, 317–335.

Lordan, O., Sallan, J.M., 2017. Analyzing the multilevel structure of the European airport network. Chin. J. Aeronaut. 30, 554–560.

Lordan, O., Sallan, J.M., Simo, P., 2014. Study of the topology and robustness of airline route networks from the complex network approach: a survey and research agenda. J. Transp. Geogr. 37, 112–120.

Matsumoto, H., 2007. International air network structures and air traffic density of world cities. Transp. Res. E 43, 269–282.

Newman, M.E., 2003. The structure and function of complex networks. SIAM Rev. 45, 167–256.

O'Connor, K., 1995. Airport development in southeast Asia. J. Transp. Geogr. 3, 269–279.

O'Kelly, M.E., 1998. A geographer's analysis of hub-and-spoke networks. J. Transp. Geogr. 6, 171–186.

Ooi, G.-L., 1995. The Indonesia-Malaysia-Singapore growth triangle: sub-regional economic cooperation and integration. GeoJournal 36, 337–344.

Paleari, S., Redondi, R., Malighetti, P., 2010. A comparative study of airport connectivity in China, Europe and US: which network provides the best service to passengers? Transp. Res. E 46, 198–210.

Phang, S.-Y., 2003. Strategic development of airport and rail infrastructure: the case of Singapore. Transp. Policy 10, 27–33.

Raguraman, K., 1997. Airlines as instruments for nation building and national identity: case study of Malaysia and Singapore. J. Transp. Geogr. 5, 239–256.

Reed, W.J., 2003. The Pareto law of incomes-an explanation and an extension. Phys. A Stat. Mech. Appl. 319, 469–486.

Rimmer, P.J., 1999. The Asia-Pacific Rim's transport and telecommunications systems: spatial structure and corporate control since the mid-1980s. GeoJournal 48, 43–65.

Rimmer, P.J., 2000. Effects of the Asian crisis on the geography of Southeast Asia's air traffic. J. Transp. Geogr. 8, 83–97.

Rimmer, P.J., Dick, H.W., 2009. The City in Southeast Asia: Patterns, Processes and Policy. NUS Press, Singapore.

Robinson, R., 2006. Port-oriented landside logistics in Australian ports: a strategic framework. Marit. Econ. Logist. 8, 40–59.

Rocha, L.E.D., 2009. Structural evolution of the Brazilian airport network. J. Stat. Mech. 2009, P04020.

Ru, W., Xu, C., 2005. Hierarchical structure, disassortativity and information measures of the US flight network. Chin. Phys. Lett. 22, 2715–2718.

Sien, C.L., 2003. Southeast Asia Transformed: A Geography of Change. Institute of Southeast Asian Studies, Singapore.

Tanaka, K., 2009. Regional Integration in Southeast Asia: Better Macroeconomic Co-operation Can Mitigate Risks. OECD Development Centre Policy Insights 90, OECD Publishing.

Taylor, P.J., Derudder, B., Hoyler, M., Ni, P., 2013. New regional geographies of the world as practised by leading advanced producer service firms in 2010. Trans. Inst. Br. Geogr. 38, 497–511.

Thant, M., 2012. Regional cooperation and the changing urban landscape of Southeast Asia. In: Sheng, Y.K., Thuzar, M. (Eds.), Urbanization in Southeast Asia: Issues &

Impacts. Institute of Southeast Asian Studies, Singapore, pp. 154–171.
Thompson, E.C., 2013. In Defence of Southeast Asia: a case for methodological regionalism. TRaNS 1, 281–302.
Tsiotas, D., Polyzos, S., 2017. The complexity in the study of spatial networks: an epistemological approach. Netw. Spat. Econ. 1–32.
Van De Vijver, E., Derudder, B., Witlox, F., 2014. Exploring causality in trade and air passenger travel relationships: the case of Asia-Pacific, 1980–2010. J. Transp. Geogr. 34, 142–150.
Verma, T., Araújo, N.A., Herrmann, H.J., 2014. Revealing the structure of the world airline network. Sci. Rep. 4, 5638.
Wandelt, S., Sun, X., 2015. Evolution of the international air transportation country network from 2002 to 2013. Transp. Res. E 82, 55–78.
Wang, J., Jin, F., Mo, H., Wang, F., 2009. Spatiotemporal evolution of China's railway network in the 20th century: an accessibility approach. Transp. Res. A Policy Pract. 43, 765–778.
Wang, J., Mo, H., Wang, F., Jin, F., 2011. Exploring the network structure and nodal centrality of China's air transport network: a complex network approach. J. Transp. Geogr. 19, 712–721.
Wang, J., Mo, H., Wang, F., 2014. Evolution of air transport network of China 1930-2012. J. Transp. Geogr. 40, 145–158.
Watts, D.J., Strogatz, S.H., 1998. Collective dynamics of'small-world'networks. Nature 393, 440–442.
Xie, F., Levinson, D., 2009. Modeling the growth of transportation networks: a comprehensive review. Netw. Spat. Econ. 9, 291–307.
Xie, F., Lin, J., Cui, W., 2015. Exploring express delivery networks in China based on complex network theory. Complexity 21, 166–179.
Xu, Z., Harriss, R., 2008. Exploring the structure of the US intercity passenger air transportation network: a weighted complex network approach. GeoJournal 73, 87–102.
Yap, J.T., 2014. Addressing Inequality in Southeast Asia through Regional Economic Integration. Institute of Developing Economies, Tokyo, Japan Retrieved from website: http://www.ide.go.jp/English/Publish/Download/Brc/pdf/14_01.pdf.
Zanin, M., Lillo, F., 2013. Modelling the air transport with complex networks: a short review. Eur. Phys. J. Spec. Topics 215, 5–21.
Zhang, A., Hanaoka, S., Inamura, H., Ishikura, T., 2008. Low-cost carriers in Asia: deregulation, regional liberalization and secondary airports. Res. Transp. Econ. 24, 36–50.