**Traffic consolidation in East Asian container ports: A network flow analysis**



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# TRAFFIC CONSOLIDATION IN EAST ASIAN CONTAINER PORTS: A NETWORK FLOW ANALYSIS

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## Abstract

The proliferation of hub-and-spoke operations in maritime container transportation has resulted in the widespread consolidation of traffic flows. Utilising liner shipping network configurations, this paper assesses the impact of freight traffic consolidation in the container port industry by exploring the spatial pattern of traffic flow movements and identifying the variety of roles that container ports play within this context. On the basis of the network concept, the spatial inequality of freight traffic consolidation is determined by the density and direction of all meaningful connections (i.e. *significant flows*) identified by applying Multiple Linkage Analysis (MLA) to an initial traffic flow matrix.

The effectiveness of the chosen methodology is tested empirically using a sample comprising the 18 major container ports in East Asia, together with another 21 important container ports located on the East-West trading route. Based on this sample network, the spatial structure of traffic flow consolidation reveals the nature and structure of hub-and-spoke operations within a port system, the relative hub-dependence of ports, the variety of roles which individual ports play within the overall structure of inter-port interactions and the hierarchical configuration of the port industry structure. The paper concludes that MLA offers new insights into the distributional inequality of traffic flows, the spatial and economic interactions between ports and the extent to which hinterlands overlap. Furthermore, the analysis clearly shows that inter-port relationships can no longer be evaluated as isolated phenomenon; any change in a specific port's competitiveness will directly impact upon the structure of the whole maritime transportation system. Port authorities and terminal operators will need, therefore, to carefully analyse and disentangle specific inter-port relationships in order to provide the most appropriate basis for their decision making.

**Keywords:** network, traffic consolidation, multiple linkage analysis, significant flow, hub-dependence.

# TRAFFIC CONSOLIDATION IN EAST ASIAN CONTAINER PORTS: A NETWORK FLOW ANALYSIS

## 1. Introduction

A significant share of the worldwide container transport market is served through hub-and-spoke operations, with traffic flow being funnelled through a number of hub ports or load centres. Increasing ship sizes, the existence of strategic alliances and other collaborative arrangements, as well as the greater industrial concentration of the liner shipping sector, have all served to fuel the continuation of this trend. As a result, container traffic has become increasingly consolidated into hub ports and the shipping lanes which connect them.

This consolidation of traffic flows in the maritime container transport system has brought significant changes to the liner shipping industry; ocean carriers have benefited greatly from reduced network construction cost, centralized cargo handling and sorting, and are able to take advantage of scale economies. An abundant literature (e.g. Gardiner, 1997; Midoro and Pitto, 2000; Sheppad and Siedman, 2001) has addressed the strategic motivation behind, and effects of, this phenomenon from the perspective of container shipping companies. However, for the port sector, the advantages of container traffic consolidation might be perceived as rather more tenuous, with only relatively few ports leveraging on this trend to either strengthen their existing status, or sometimes even to emerge as new hub ports. The majority of ports, on the other hand, have been left having to face the consequences of intensified competition from their rivals.

This paper aims to assess the impact of freight traffic consolidation in the container port industry by exploring the spatial pattern of traffic flow movements and identifying the variety of roles that container ports play within this context. In so doing, the container port system is analysed on the basis of the liner shipping network, where ports constitute the nodes and container shipping services provide the links.

An approach based in Graph Theory, known as Multiple Linkage Analysis (MLA), is described and applied to reveal the 'significant flows' within a network; where a set of interacting nodes holds some relationships which are significant within the overall flow pattern. Utilising this as the basis, the spatial structure of traffic flow consolidation is illustrated and the hierarchical configuration of the port industry structure is visualised to yield a better understanding of the distributional inequality of traffic flows and the extent to which hinterlands overlap.

The remaining sections of this paper start with a review of research into container freight traffic consolidation and other relevant areas in section 2. Section 3 deals with the theoretical framework and provides an exposition of the Multiple Linkage Analysis that is employed for the ensuing analysis. An empirical study applying the approach is detailed in section 4. Finally, the implications of the research findings and some conclusions are drawn in Section 5.

## 2 Review of freight traffic consolidation research

Freight traffic consolidation in the container port industry has emerged as a by-product of the process of industrial concentration that has characterised both maritime container shipping and container handling over the past two decades. From the earliest systematic concentration analysis (Taaffe et al., 1963; Rimmer, 1967) to the promulgation of the load centre concept (Hayuth, 1981) and later, a consensus exists among industry analysts that relatively few large and rapidly expanding container ports have asserted their dominance in the industry and have expanded themselves into hub ports or fully-fledged container load centres. This situation is characterised by a significant share of container traffic flows originating from feeder ports for consolidation and funnelling through the more dominant hub/load centre ports for onward movement to a diverse range of destination ports. This contemporary context has emerged as the result of a combination of determining factors: the greater market penetration of the major shipping lines; increasing concentration in the global container handling industry, largely on the back of international diversification through acquisition strategies; the trend towards the use of dedicated terminals and the vertical integration of container shipping companies into the common user container handling sector; the continuous increase in ship size and the various forms of co-operation between liner operators (ECLAC, 1998; Cullinane and Khanna, 1999; 2000). All of these factors have combined to lead to the emergence of container shipping networks which revolve around the hub-and-spoke concept, an important corollary of which has been the greater consolidation of traffic flows not only at individual, dominant hub/load centre ports, but also in shipping lanes which link these ports.

The major focus of most previous relevant research has been the level of industrial concentration within the container port sector (generally using container throughput as the most pertinent indicator of this) and to examine the changes in market structure over time. For instance: Marti (1988) and Hayuth (1988) examined container traffic concentration in the North American market by applying Shift-Share Analysis and the Gini coefficient; Notteboom (1997) investigated the concentration and deconcentration tendencies of port traffic to reveal how load centre development had occurred in the European port system over the period 1980-1994; Wang and Cullinane (2004) applied the Hirshman-Herfindahl Index, the Gini coefficient and Shift-Share Analysis to the Hamburg-Le Havre range, the U.S. west and east coast and Southern China for examining port traffic concentration between 1992 and 2002; Notteboom (2006) again provided a further understanding of traffic concentration in seaport systems by introducing three criteria in grouping port ranges and calculating the overlapping effect of traffic inequality between port ranges.

Most of the above studies have identified a significant tendency towards the concentration of port traffic or, more specifically by inference, towards the consolidation[1] of container flows. However, an important shortcoming of these previous studies is their use of concentration measures based on port throughput; when attempting to undertake a formal investigation of traffic consolidation as is the intention herein, throughput does not constitute an appropriate unit of analysis because of both its lack of information on container origins and destinations, as well as the problem of double-counting transhipment cargo (Veenstra et al., 2005). It is for this reason that it has not been possible for these previous studies to address issues such as the hierarchy of container ports as determined by the nature and structure of hub-and-spoke operations, relative hub-dependence and the variety of roles which individual ports play within the overall structure of inter-port interaction. It is this gap in the literature which this work seeks to plug.

In addition, freight traffic consolidation in the container shipping industry has led to a significant alteration in inter-port relationships which, in consequence, has affected the strategies and practices adopted by port management. Technological development, containerization in particular, has provided greater freedom to serve markets from a wider choice of port (Fleming and Hayuth, 1994) and, in consequence, most individual ports no longer have exclusive control over inland markets and can no longer be sure that trade even in their own local areas is secure (Slack, 2001). As the primary clients of ports, shipping companies are now showing less loyalty to a particular port, but move their traffic over the route which offers the best outcome in terms of overall service provision. In consequence, competition between ports has become the key issue in deciding upon both short and long term port development plans. On the other hand, existence of a complementary relationship between adjacent ports has also been identified in both regional port development studies

[1] This is our preferred term for this phenomenon, as utilised throughout the rest of the paper.

(e.g. Notteboom and Winkelmans, 1999) and the routing and scheduling optimization of liner shipping services (e.g. Yap and Lam, 2006; Lam, 2011 etc.). This, of course, renders inter-port relationships, as well as their analysis, even more complicated.

Existing studies about inter-port relationships are generally conducted at an aggregate level. For example, since the 1980s, much attention has been paid to the assessment of port competitiveness, the analysis of port governance, port policy and strategy and carriers' port selection or preferences etc. However, to simply refer to inter-port relationships in general terms such as 'the competitive position of port X' or 'the competition/cooperation between port X and Y' may not be particularly meaningful or useful. Instead, greater benefits may be derived from carefully classifying inter-port relationships in terms of their *extensiveness and/or intensity in specific markets* (Verhoeff, 1981). The latter, for example, is particularly affected by the fact that different ports vary by: their geographical nature (e.g. with either direct or indirect overlapping of hinterlands); the products and services offered (e.g. as a gateway or transhipment port) and; shipping companies involved (e.g. not all carriers coincide in their choice of regional load centres). Thus, for meaningful insights, inter-port relationships must be investigated either on a case by case basis or, as proposed herein, more holistically by examining the interactivity between ports on the basis of a standard metric. Information on container traffic or shipping capacity flows with identifiable origins and destinations provides the ideal basis for such an analysis as such data can be taken to represent both the spatial and economic interactions among ports.

## 3 Network flow analysis of container traffic consolidation

Within the context of spatial network analysis, the consolidation of maritime container traffic is a structural feature of the system that indicates how individual and, possibly, sub-groups of container ports are competitively positioned with respect to each other. By applying graph-theoretic considerations, an investigation of network flow data, which is both weighted by traffic flow and directed in terms of the origin and destination of those flows, can reveal a whole range of spatial typologies, as well as the skeleton of the nodal organisation of the geographical area analysed (Haggett et al., 1977).

More importantly, the position (role) of a container port within a liner shipping network is no longer simply determined by the size of its throughput, capacity or any other technical indicators, but by the nature of the flows into and out of the port. Moreover, the spatial 'profile' of the total flow through a particular port can also highlight potential differences in the configuration of ports with a similar level of traffic flow, while the distributional inequality of the spatial make-up of total flow indicates the relationships between ports.

### 3.1 Multiple Linkage Analysis (MLA)

MLA is a well-developed extension of Primary Linkage Analysis due to by Nystuen and Dacey (1961), who claimed that there exists a relationship between a hierarchy of locations and the pattern of flows between those locations. The core concept of primary linkage analysis may be summarised as being the determination of whether the *dominated outflow* originating from any single node is directed to another one which is considered more or less important on the basis of some variable of interest. In other words, a node is determined as 'independent' if its 'largest outflow' is to a 'less important' node. Conversely, a node exhibits 'dependence' when its 'largest outflow' is associated with a 'more important' node. The omportance of a node within this context is pre-defined by an externally assigned attribute (e.g. pollution, GDP, total traffic volume etc.).

Figure 1 illustrates this principle as applied by Nystuen and Dacey (1961) to a sample network structure of cities linked by telephone messages. In their example application, the 'Importance' of each city is determined by its total incoming messages received (i.e. the column totals) and the entries in the original adjacent matrix represent the intensities and directions of functional associations between pairs of cities. By focusing on the movement of the 'largest outflows' from each city, the original adjacent matrix was abstracted and refined to a nodal structure which indicates the dependent relationship between pairs of cities, as well as those "independent" cities without outward connections.. This is then represented by the nodal diagrams and the arrows drawn between the city nodes,

**INSERT FIGURE 1**

Based on practical experience of using this approach, however, it suffers from three major shortcomings: a) the importance/hierarchy of nodes is defined on the basis of a single attribute or variable of interest (e.g. population, economic scale, sum of inflows etc.), which is not sufficient enough to represent its position or hierarchy within the network, b) only the maximum outflow from each node is taken into account, such that the rest of the information in the O-D matrix is wasted, and c) it may lead to erroneous conclusions when simply the greatest flow alone is considered (Peubla, 1987). To illustrate these shortcomings, Figure 2 shows two distinct examples of outflow distributions, although in each case $O \rightarrow D_3$ is the dominant (largest) outflow. This is all that Primary Linkage Analysis would be concerned with. However, while the freight flow distribution shown in (a) is highly concentrated on this link, that shown in (b) radiates into a more evenly spread distributional pattern. It would appear to be inappropriate to define the network structure of graph (b) as revolving totally around the dependence of the origin node O on the destination node $D_3$. The links $O \rightarrow D_2$ and $O \rightarrow D_4$ simply cannot be ignored, due to their relatively significant influence on the entire network.

**INSERT FIGURE 2**

MLA overcomes these disadvantages by emphasizing the "intensity" and "direction" of flows between places (Rabino, 1997), rather than ranking nodal locations on the basis of a single variable of interest prior to any subsequent analysis of flows. Under MLA, the relationship between any pair of nodes is no longer determined by the movement of the *dominant flow*, but by the existence of meaningful connections between them, referred to as *significant flow*, and whose value is greater than a given threshold. In other words, *significant flows* indicate the 'saliency' of the relationships – any change to, or elimination, of those linkage connections will affect the spatial configuration of the entire network (Brown and Holmes, 1971; Rabino, 1997). As a consequence, the relative importance of nodal locations is determined ex-post and depends on the spatial configuration of all *significant flows*.

In applying MLA, all outflows from a node are ranked from the largest ($w_1$) to the smallest ($w_k$). A set of cycles of expected flows $\{\widehat{w}_i\}$, with i∈K (the set of nodes within the network), is then generated as follows (Haggett et al., 1977):

1st step: $\widehat{w}_1 = \sum_{i=1}^{k} w_i$ $\widehat{w}_2 = \widehat{w}_3 = \cdots = \widehat{w}_k = 0$

2nd step: $\widehat{w}_1 = \widehat{w}_2 = \frac{1}{2}\sum_{i=1}^{k} w_i$ $\widehat{w}_3 = \widehat{w}_4 = \cdots = \widehat{w}_k = 0$

jth step (j<k): $\widehat{w}_1 = \widehat{w}_2 = \cdots = \widehat{w}_j = \frac{1}{j}\sum_{i=1}^{k} w_i$ $\widehat{w}_{j+1} = \widehat{w}_{j+2} = \cdots = \widehat{w}_k = 0$

kth step: $\widehat{w}_1 = \widehat{w}_2 = \cdots = \widehat{w}_k = \frac{1}{k}\sum_{i=1}^{k} w_i$

The set of expected flows $\{\widehat{w}_i\}$ represents the spatial structure of all flows out of node i. The goodness of fit between the set of observed flows and each of the sets of expected flows is measured by the coefficient of determination ($r^2$). The number of significant flows corresponds to the jth cycle with the highest $r_j^2$ value (see Table 1).

**INSERT TABLE 1**

## 3.2 The meaning of *significant flow*

Significant flows are identified due to their dominance (not necessarily as the largest) in overall traffic flow distribution through each node, and reveal the skeleton of network structure. The direction of their movements further indicates the diversity of 'roles' each individual node plays within the network and the nature of the relationship between each pair of nodes. As pointed out by Kipnis (1985) significant outflows indicate the most favourable destinations of flows from one node to another, while significant inflows depict the prominent source of flows into a node.

### *3.2.1 Hierarchical clustering*

Following the application of the MLA procedure, only significant connections are retained within the sample liner shipping network. To assess the hierarchy of ports within this network, however, it will not be necessary to compare the number of significant inflows or outflows on a port-by-port basis. In practical terms, there is no sense in assessing the hierarchical order of the ports of Tianjin and Xiamen, for example, as they are both local gateway ports and serve different hinterlands. Since this paper attempts to address the diversity of available services in scale and scope and, thereby, to examine the consolidation which has occurred in maritime container transportation within the East Asian region, a hierarchical clustering analysis is applied to the ports on the basis of the reconstructed liner shipping network, consisting solely of significant capacity flows alone. The geographical level of container handling services offered by East Asian ports can be classified into the three categories of local, regional and international, with ports playing more of a transhipment role as they increase in hierarchical level.

Within the context of this paper, the number of significant inflows through ports, which is positively related to its popularity as a destination within the system, is selected as the variable of interest in this sub-analysis in order to ensure that the spatial make-up of flow capacity is also considered. This analysis of hierarchical clustering is undertaken using XLminer, a specialised data mining tool for classification, regression trees, association rules etc.

*3.2.2 Flow movements and network relationships*

As mentioned previously, Primary Linkage Analysis (PLA) is mainly focused on the dominant and dominated flows into and out of nodes and thereby defines the inter-node relationship as 'dependence' or 'independent'. This is obviously insufficient when the concepts of competition and complementarity are taken into account. A further investigation of the spatial features of network flow movement is essential in explaining the interdependence between the structure of space and the interactions which exist across space (Wheeler, 1973).

Utilising the characteristics of significant flow movements, a series of network relationships are defined against the different dispersion patterns of flow distribution associated with nodes (see Table 2). The hierarchical network structure derived from applying MLA to the geographically "clustered" port ranges of the East Asian container port industry is utilised for the categorisation of links in terms of these relationships. The aim is to identify the extensiveness and intensity of inter-port complementarity and competition for a specific container port market.

**INSERT TABLE 2**

## 4 Case study of the East Asian container port industry

The liner shipping network analyzed within the context of this paper consists of 18 major container ports in East Asia; a geographical region which has been chosen not only because of its dominant role in worldwide container transportation, but also because of the intense inter-port competition which exists within the region. The 18 major container ports are geographically scattered along three port ranges, with 8 in the North-Eastern range, 6 in the Central-Eastern range and 4 in the South-Eastern range. In order to cater for the prospective pivotal role of these ports within intercontinental routes, 21 additional container ports from East Asia's four major trading markets are also included within the sample network of major international container ports; with Europe contributing seven, the Middle-East four, North America five and the Mediterranean also five (see Table 3).

**INSERT TABLE 3**

In terms of network connections, a linkage (i.e. flow) value is defined as the combined weekly transportation capacity (in TEUs per week) deployed by the top 20 liner shipping companies and applies to each of the linkages between all pairs of ports. This is due to not only the difficulty in obtaining the required data on the actual transported quantities of containers from a given set of origins to a given set of destinations, but also the high correlation between shipping capacity deployed and actual market demand. Thus, transportation capacity between any pair of ports is proposed as a proxy indicator of actual traffic flows in the construction of the liner shipping network analyzed in the present study. In addition, the direction of capacity flow movement is also taken into account due to its significance in network flow analysis.

### 4.1 Hierarchical illustration of freight traffic consolidation

Figures 3 and 4 show the sample network configuration derived from utilizing the approaches of PLA and MLA respectively. In the former, the port hierarchy was pre-defined in terms of the total capacity flow through a port, and thereby, the illustrated network structure is derived by following the movements of dominant/dominated flows between ports. Accordingly, the ports of Hong Kong, Singapore, Shenzhen, Shanghai and Klang are centrally positioned within the sample network as a consequence of their strong "hub" characteristics, while the rest serve as "dependent" ports surrounding them. Unfortunately and as shown earlier, this abstracted single relationship network has minimal practical meaning and use, due to the significant loss of network flow information apart from that relating to the dominant links. For example, as shown in Figure 3, the port of Tokyo appears to feature more in terms of providing a transhipment function than Busan. This is due to the inflows from the ports of Nagoya and Kobe, but obviously conflicts with the actual situation in practice.

**INSERT FIGURE 3**

**INSERT FIGURE 4**

In contrast, determining network structure by applying MLA is rather complicated. All nodes within the network are connected through the significant flows between pairs of ports, while the size of each node (i.e. the relative importance of each port within the system) is determined by the number of significant inflows associated with that port[2]. As shown in Figure 4, the ports of Shenzhen, Hong Kong, Shanghai and Singapore are all positioned within the highest tier cluster and hold a significant advantage in terms of the total significant inflow numbers; each of them has more than 20 out of 39 in total. The second tier cluster consists of the ports of Busan, Kaohsiung, port Klang and Ningbo, all of which surround the

[2] The closely associated relationship between port hierarchy and the number of significant inflows is evidenced in Cullinane and Wang (2012).

4 ports within the top tier cluster, with each holding between 9 to 12 significant inflows respectively. The remaining 10 ports are mainly local gateway ports and sit within the lowest tier cluster, with each having less than 6 significant inflows.

The presence and movement of significant flows over the network provide some interesting insights into the nature of container freight traffic consolidation in East Asia. For intra-regional connections, as summarised in Table 4, the major origins of significant inflows to the ports in cluster 3 are from ports at the same level, particularly those with a shared hinterland. This is largely the result of the existence of strong connections within specific sub-regions. Conversely, all significant outflows originating from the ports within cluster 2 and 3 generally move toward the ports located at a higher level. This is very much facilitated by the prevalence of hub-and-spoke operations. Outflows from the ports of Singapore, Hong Kong, Shenzhen and Shanghai can be seen to move towards ports within the same cluster. All this provides an explanation for the scale of shipping capacity on the linkages between these four ports, which is far greater than on other links within the network.

**INSERT TABLE 4**

For intercontinental container movements, the analysis conducted herein focuses solely on services operated by the top 20 liner shipping companies. Indeed, the major involvement of this group of operators rests with container transportation services on intercontinental routes. Due to rapid economic growth in East Asia, a significant proportion of the outflow of shipping capacity for any port located outside that region will move towards East Asia. Moreover, in practice, any service with flows moving towards East Asia will always call at one or more ports within cluster 1, no matter which port they are finally destined for. As a result, this not only reinforces the dominant role of ports within cluster 1 in intercontinental connections, but also leads to a high level of concentration of regional capacity deployed. The emergence of cluster 2 is due to the same reason, but with a significant dependence on the geographical location of individual ports within the cluster. For example, apart from significant inflows from the ports within their hinterland, the ports of Busan and Kaohsiung mainly attract significant connections from the North American market, while Port Klang mainly receive inflows from Europe, the Mediterranean and the Middle East. By considering each trading market as a whole, all meaningful connections are illustrated in Figure 5. On the Far East – Europe route, the ports of Shanghai and Ningbo in the Yangtze River Delta, Hong Kong and Shenzhen in the Pearl River Delta and Singapore and Port Klang in South-East Asia all have a competitive capacity advantage over others in the region. Due to their strategic location, the ports of Busan and Kaohsiung play a significant role in handling containers to and from the North American market while, for the same reason, Singapore and Port Klang have lost their influence on the transpacific route..

**INSERT FIGURE 5**

Finally, the spatial pattern of network flow movement in East Asia also reveals the co-existence of multi-dimensional hub-and-spoke structures, together with extensive direct international shipping connections. As mentioned above, bottom-up movements of significant flows provide strong evidence of the hub-and-spoke features of regional container transportation. However, as can be found in Figure 4, a significant proportion of hierarchical flows is moved on the basis of the inter-port range, which suggests that there are several hubs or load centres that co-exist within the current industrial structure and that their corresponding hub-and-spoke channels may either be competing with, or are complementary to, one another (Wang and Ng, 2009). On the other hand, traditional hub ports like Hong Kong and Singapore no longer exert dominant control over international connections with major ports outside of East Asia. Instead, numerous direct calls are now scheduled for Mainland Chinese ports, due to the rapid economic growth of their hinterlands. Within the context of this analysis, the ports of Shenzhen and Shanghai have successfully positioned themselves at the same level within the region's port hierarchy as Hong Kong, while other gateway ports also attract significant international flows

**4.2 Inter-port competition and complementarity**

The visualising of significant flow movements is also helpful in exploring inter-port relationships. Inter-port competition and complementarity can be identified by examining the dispersion patterns of flow distribution associated with nodes. Competition occurs when two ports share a common origin of significant inflows in a specific market, while complementarity is indicated by a dual directional movement of significant flows between pairs of geographically adjacent ports. Figure 6 below illustrates all intra-regional significant flow movements in East Asia.

**INSERT FIGURE 6**

*Northeast Asia*

The Northeast Asian market is primarily served by local gateway ports with less competitive hinterland economies than the other two port ranges. The port of Busan serves as the regional transhipment centre through its cost-competitive and efficient operations. As can be observed from Figure 6, port competition in this region exists in both intra- and inter-port range levels. First of all, Qingdao is the most competitive container port around the Bohai Bay area (Northeast China), and has a direct competitive rivalry with the port of Busan in terms of attracting container traffic from Dalian and Tianjin. Secondly, the absence of any real pattern in the movement of significant flows between the four Japanese ports suggests a relative absence of concentration within the container port system in Japan. As a result, outflows from the Japanese market are much more likely to be transhipped via other ports for the purpose of international shipping. In this respect, the port of Busan, as a newly emerged regional transhipment centre, has to compete with Kaohsiung, Hong Kong and even Shanghai to secure the hinterland market of Japan. In addition, inter-port complementarity within this port range is also indentified within the Japanese port industry, in that dual directional significant connections exist between Tokyo and Yokohama, Nagoya and Tokyo, and Nagoya and Yokohama. This can be mainly attributed to changes in the service calling pattern in Japan whereby, due to the lack of opportunity for reaping scale economies, the trunk lines reduced the number of ship calls in Japanese ports by stopping at different ones each time (Hoshino, 2010).

*Central East Asia*

Inter-port relationships in the Central East Asian port range are dominated by the co-existence of inter-port competition and complementarity, both between Hong Kong and Shenzhen in the Pearl River Delta and between Shanghai and Ningbo in the Yangtze River Delta. As addressed in much of the literature (Wang, 1998; Wang and Slack, 2000; Song, 2002; Seabrooke et al, 2003; Cullinane et al, 2004; Wang and Slack, 2004; Cullinane et al, 2005; Yap and Lam, 2006; Yap et al, 2006; Comtois and Dong, 2007), these two pairs of ports are engaged in intense inter-port competition due to their geographical proximity and, therefore, the significant overlapping which exists between their hinterlands. At the same time, however, the economic boom in these two regions has prompted shipping companies to reorganise their service schedules and ports-of-rotation to exploit the growing traffic density and achieve greater network economies. Therefore, the interdependent relationship between these two pairs of ports, no matter from a political or economic perspective, is likely to be characterised as ‘co-opetition’ (Song, 2003).

*Southeast Asia*

As indicated by the significant connections associated with the sample ports, the container handling business in Southeast Asia is largely concentrated within the ports of Singapore, Port Klang and Tanjung Pelepas, while the port of Laem Chabang serves more or less as a local gateway port that relies on the hubs of both Singapore and Hong Kong.

The port of Singapore is the dominant transhipment hub in the region as a result of attracting significant flows originating from both local and other inter-range ports. However, the inter-range flows associated with port Klang and Tanjung Pelepas also evidence their emergence as competitive alternatives for transhipment operations. In the case of port Klang, significant inflows originated from the central East Asia port range, suggesting that it is utilized as a transhipment centre for connecting European, Middle-East and Mediterranean markets. Similarly, the significant outflows of Tanjung Pelepas exhibit quite a dispersed pattern, largely due to the hub relocation of Maersk from Singapore to this port.

Inter-port complementarity was found to exist between Singapore and port Klang, since both have significant flows towards each other. The main reason behind this is slightly different from the cases of Hong and Shenzhen and Shanghai and Ningbo; although different shipping companies may have different thoughts regarding their preferred hub location in Southeast Asia, most prefer to call at both ports in order to strengthen their service connectivity to particular trade routes and regions (Yap and Notteboom, 2009).

## 5 Research implications and conclusions

As an alternative to traditional methods of investigating industrial structure, network analysis offers new insights for policy and research. The core concept of this paper is that the consolidation of maritime freight traffic can be treated as a structural feature of the international container transport system and that it indicates how individual and, possibly, sub-groups of ports are competitively positioned with respect to each other. On the basis of the network concept, the spatial inequality of freight traffic consolidation has been illustrated by the density and direction of all meaningful connections (i.e. significant flows) identified by applying Multiple Linkage Analysis (MLA) to an initial traffic flow matrix. As a consequence, the nature and structure of hub-and-spoke operations within a port system, relative hub-dependence and the variety of roles which individual ports play within the overall structure of inter-port interactions are unveiled in order to support and inform future policy and decision making.

The empirical results of this study suggest that the spatial configuration of ports within East Asia is characterised by the complex co-existence of a multi-dimensional hub-and-spoke structure, together with point-to-point direct international connections. What this means is that there are several hubs/load centres that co-exist within the current industrial structure and that their corresponding hub-and-spoke channels may either be competitive with, or complementary to, one another. Analysing container traffic information from the perspective of network flow movement, in particular the density and directions, has proved to be extremely helpful in identifying these spatial and economic interactions between ports. Furthermore, the analysis has shown that inter-port relationships can no longer be evaluated as isolated phenomenon; any change in response to the improvement of a specific port's competitiveness will directly impact upon the structure of the whole maritime transportation system. It is therefore essential for port authorities and terminal operators to carefully investigate and disentangle specific inter-port relationships in order to provide the most appropriate basis for their decision making and subsequent actions.

The inter-port complementarity identified in this study also raises the issue of the consistency between port policies and regional development strategy. For example, the ports of Shanghai and Ningbo have both greatly benefited from the rapid economic growth of the Yangtze River Delta, but compete directly with each other in attracting cargo generated within their considerably overlapping hinterlands. The inter-port complementarity which has been found to exist between Shanghai and Ningbo only becomes evident, however, as the result of the actions of shipping companies who attempt to take advantage of traffic density and achieve greater network economies. It is decidedly not due to any interest or effort in pursuing any form of mutually beneficial collaboration. In order to secure long term competitive advantage for the whole port range and to facilitate regional economic growth, however, political coordination and some form of cooperative agreement between municipal/provincial government, port authorities and other relevant stakeholders needs to be developed accordance with the regional development strategy of China's central government. This is a strategy which has long been pursued in the relationship between the ports of Hong Kong and Shenzhen.

A further contribution of this paper is that the methodology applied herein determines the hierarchical position of a port, based on assessing its relative importance within the whole container transportation system, rather than being based solely on port throughput or any other particular features of an individual port's development or characteristics (Cullinane and Wang, 2012). In terms of added-value, therefore, the approach takes account not only of these basic port characteristics, but also of the geographical features of the sample ports in terms of their position within a spatial network and the density and direction of flows between them.

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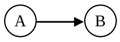
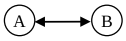
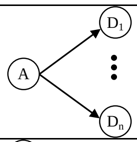
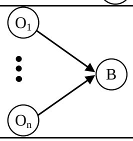
**Table 1: Identification of significant flows**

| Spatial Make-up of flows | | | | | Ideal-typical configuration | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Connected nodes | Rank | Observed flows | % Total | Expected flows | 1st step | 2nd step | … | jth step | … | kth step |
| $n_1$ | 1 | $w_1$ | $\frac{w_1}{w}*100$ | $\hat{w}_1$ | 100 | 50 | | $\frac{1}{j}$*100 | | $\frac{1}{k}$*100 |
| $n_2$ | 2 | $w_2$ | $\frac{w_2}{w}*100$ | $\hat{w}_2$ | 0 | 50 | | $\frac{1}{j}$*100 | | $\frac{1}{k}$*100 |
| … | … | … | … | … | … | … | | … | | $\frac{1}{k}$*100 |
| $n_j$ | j | $w_j$ | $\frac{w_j}{w}*100$ | $\hat{w}_j$ | 0 | 0 | … | $\frac{1}{j}$*100 | … | $\frac{1}{k}$*100 |
| $n_{j+1}$ | j+1 | $w_{j+1}$ | $\frac{w_{j+1}}{w}*100$ | $\hat{w}_{j+1}$ | 0 | 0 | | 0 | | $\frac{1}{k}$*100 |
| … | … | … | … | … | … | … | | … | | $\frac{1}{k}$*100 |
| $n_k$ | k | $w_k$ | $\frac{w_k}{w}*100$ | $\hat{w}_k$ | 0 | 0 | | 0 | | $\frac{1}{k}$*100 |
| Total | | $w$ | 100 | | 100 | 100 | … | 100 | … | 100 |
| COD | | | | | $r_1^2$ | $r_2^2$ | | $r_j^2$ | | $r_k^2$ |

Note: nodes $n_i$ correspond to the actual connecting nodes
COD = Coefficient of Determination
Source: summarised by authors

**Table 2: Significant flow movements and their implications for network relationships**

| Spatial Structure | Item Description | Implications on Inter-Node Relationship |
|---|---|---|
|  | Significant outflow of A is exclusively moving toward B; | A shows high "dependence" on B; |
|  | A and B both have significant outflows toward each other; | Complementarity between A and B when they are physically adjacent; |
|  | Significant outflows of A heading to two or more destination nodes; | Potential competition among destination nodes with the objective of outflow from A; |
|  | Significant inflows of B from two or more origin nodes. | "Hub" features of B indicated by significant inflows from surrounding node. |

Source: Summarised by authors

**Table 3: Major container ports of the sample liner shipping network**

| East Asia | | | Europe | North America | Middle East | Mediterr-anean |
|---|---|---|---|---|---|---|
| North East Asia | Central East Asia | South East Asia | | | | |
| Busan | Shanghai | Singapore | Rotterdam | New York* | Dubai | Valencia |
| Tokyo | Hong Kong | Port Kelang | Antwerp | Los Angeles | Salalah | Algeciras |
| Yokohama | Shenzhen | Tanjung Pelepas | Hamburg | Long Beach | Khor Fakkan* | Gioia Tauro |
| Kobe | Ningbo | Laem Chabang | Bremen* | Vancouver BC | Shahid Rajaee | Marsaxlokk |
| Nagoya | Kaohsiung | | Felixstowe | Oakland | | Barcelona |
| Dalian | Xiamen | | Zeebrugge | | | |
| Qingdao | | | Le Havre | | | |
| Tianjin | | | | | | |

**Table 4: Hierarchical clustering of major container ports in East Asia**

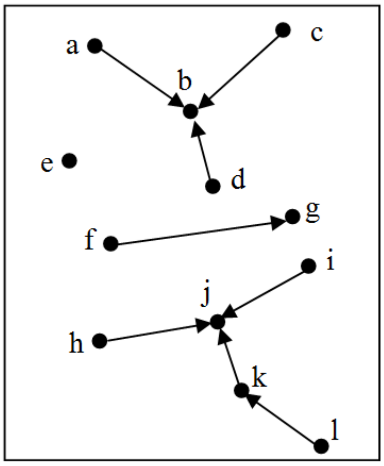
| Cluster | Port Name(*) | Number of Sig. inflows | Origins of Sig. inflows | Number of Sig. outflows | Destinations of Sig. outflows |
|---|---|---|---|---|---|
| 1 | Singapore(1) | 20 | Worldwide | 7 | Mainly towards ports within the same cluster |
| | Shanghai(2) | 21 | | 3 | |
| | Hong Kong(3) | 29 | | 2 | |
| | Shenzhen(4) | 25 | | 5 | |
| 2 | Busan(5) | 11 | Ports within cluster 3 and some inward international connections depending on geographical location | 5 | Ports within cluster 1 |
| | Ningbo(8) | 9 | | 4 | |
| | Kaohsiung(12) | 10 | | 2 | |
| | Port Kelang(13) | 12 | | 6 | |
| 3 | Qingdao(9) | 6 | Ports with shared hinterland within the same cluster and a few connections from international trading market | 2 | Mainly toward the ports within cluster 1 and 2. Also, some connections with ports within the same cluster |
| | Tianjin(11) | 6 | | 5 | |
| | Tanjung Pelepas(17) | 0 | | 11 | |
| | Xiamen(19) | 3 | | 2 | |
| | Laem Chabang(20) | 0 | | 2 | |
| | Dalian(22) | 4 | | 3 | |
| | Tokyo(26) | 6 | | 7 | |
| | Yakohama(38) | 5 | | 7 | |
| | Kobe(46) | 4 | | 6 | |
| | Nagoya(50) | 4 | | 6 | |

Note: Numbers in parentheses refer to the world rankings of port container throughput in 2009
Source: Calculated and summarised by authors on the basis of service data from www.ci-online.co.uk

**Figure 1: Illustration of network structure in Primary Linkage Analysis**

| | *a* | *b* | *c* | *d* | *e* | *f* | *g* | *h* | *i* | *j* | *k* | *l* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *a* | 0 | **75** | 15 | 20 | 28 | 2 | 3 | 2 | 1 | 20 | 1 | 0 |
| *b** | 69 | 0 | 45 | 50 | 58 | 12 | 20 | 3 | 6 | 34 | 4 | 2 |
| *c* | 5 | **51** | 0 | 12 | 40 | 0 | 6 | 1 | 3 | 15 | 0 | 1 |
| *d* | 19 | **67** | 14 | 0 | 30 | 7 | 6 | 2 | 11 | 18 | 5 | 1 |
| *e** | 7 | 40 | 48 | 26 | 0 | 7 | 10 | 2 | 37 | 39 | 12 | 6 |
| *f* | 1 | 6 | 1 | 1 | 10 | 0 | **27** | 1 | 3 | 4 | 2 | 1 |
| *g** | 2 | 16 | 3 | 3 | 13 | 31 | 0 | 3 | 18 | 8 | 3 | 1 |
| *h* | 0 | 4 | 0 | 1 | 3 | 3 | 6 | 0 | 12 | **38** | 4 | 0 |
| *i* | 2 | 28 | 3 | 6 | 43 | 4 | 16 | 12 | 0 | **98** | 13 | 1 |
| *j** | 7 | 40 | 10 | 8 | 40 | 5 | 17 | 34 | 98 | 0 | 35 | 12 |
| *k* | 1 | 8 | 2 | 1 | 18 | 0 | 6 | 5 | 12 | **30** | 0 | 15 |
| *l* | 0 | 2 | 0 | 0 | 7 | 0 | 1 | 0 | 1 | 6 | **12** | 0 |
| Column Total | 113 | 337 | 141 | 128 | 290 | 71 | 118 | 65 | 202 | 311 | 91 | 39 |

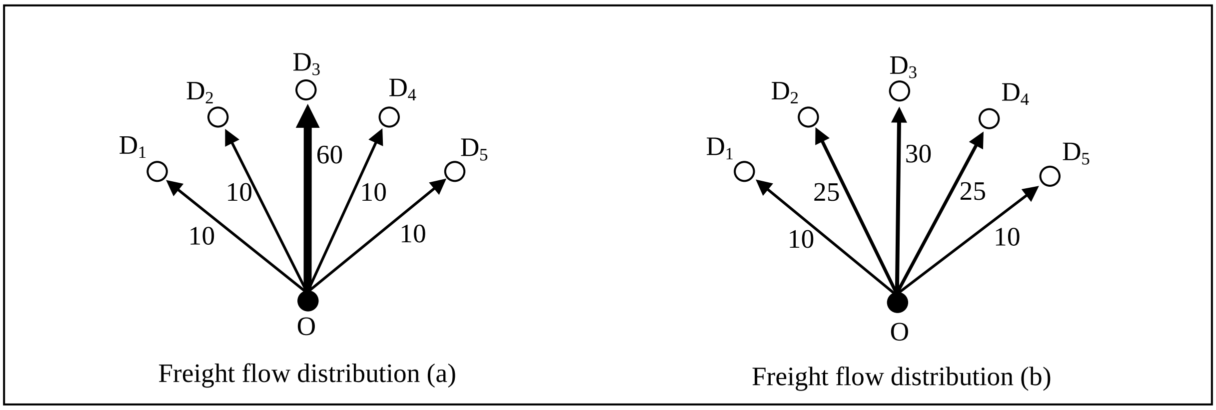
Original Connectional Matrix




Graph of the Nodal Structure

Source: Adapted from Nystuen and Dacey (1961)

**Figure 2: Diversity in freight flow distribution**

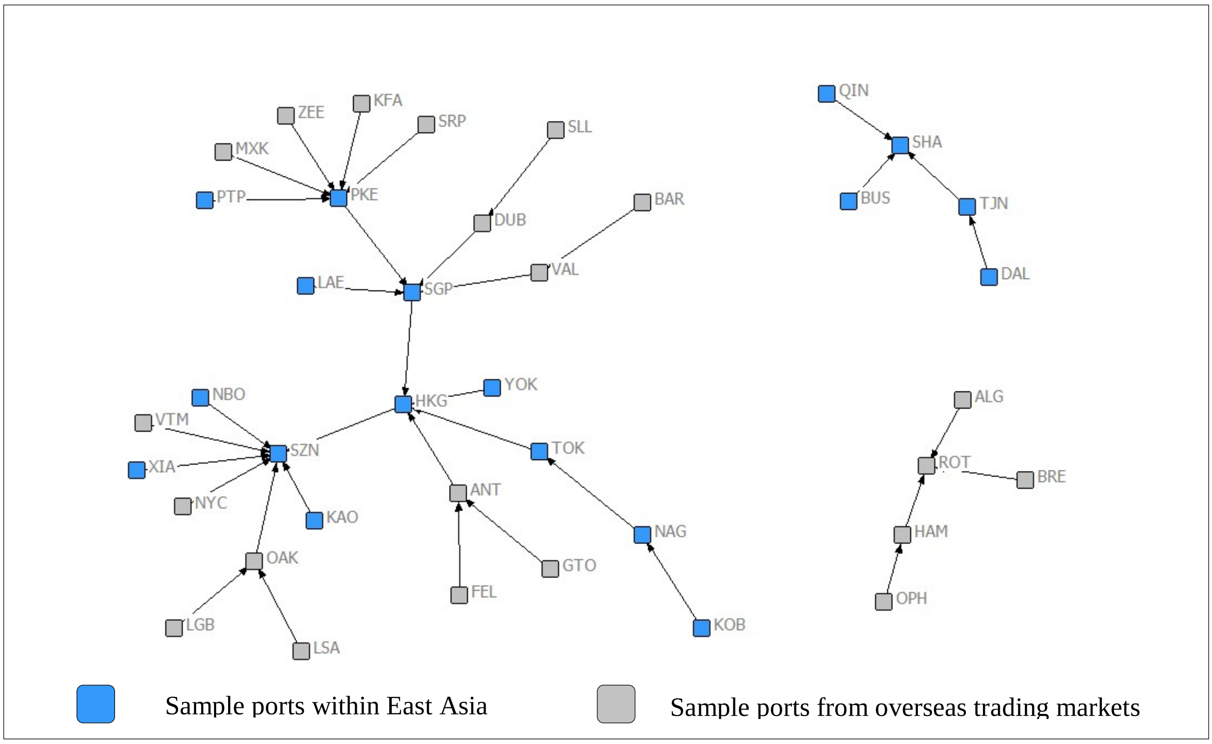



Freight flow distribution (a)

Freight flow distribution (b)

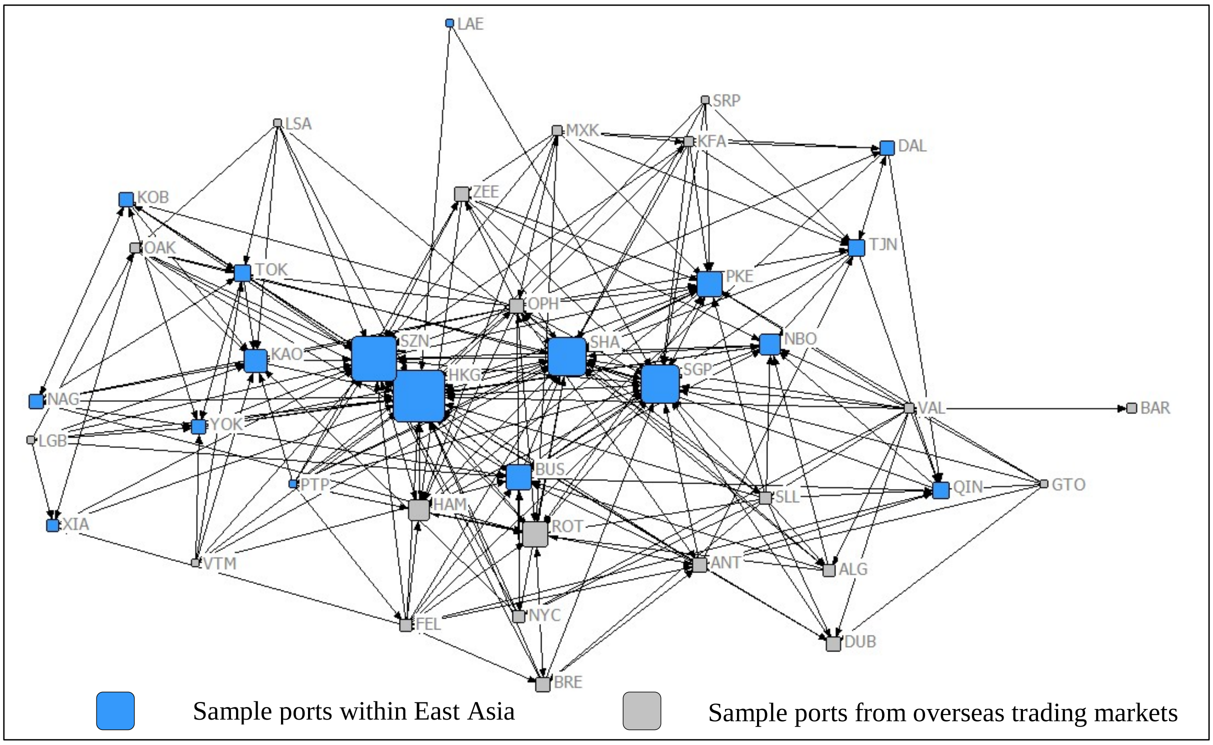
Source: Drawn by authors

**Figure 3: Sample network configuration with Primary Linkage Analysis (PLA)**



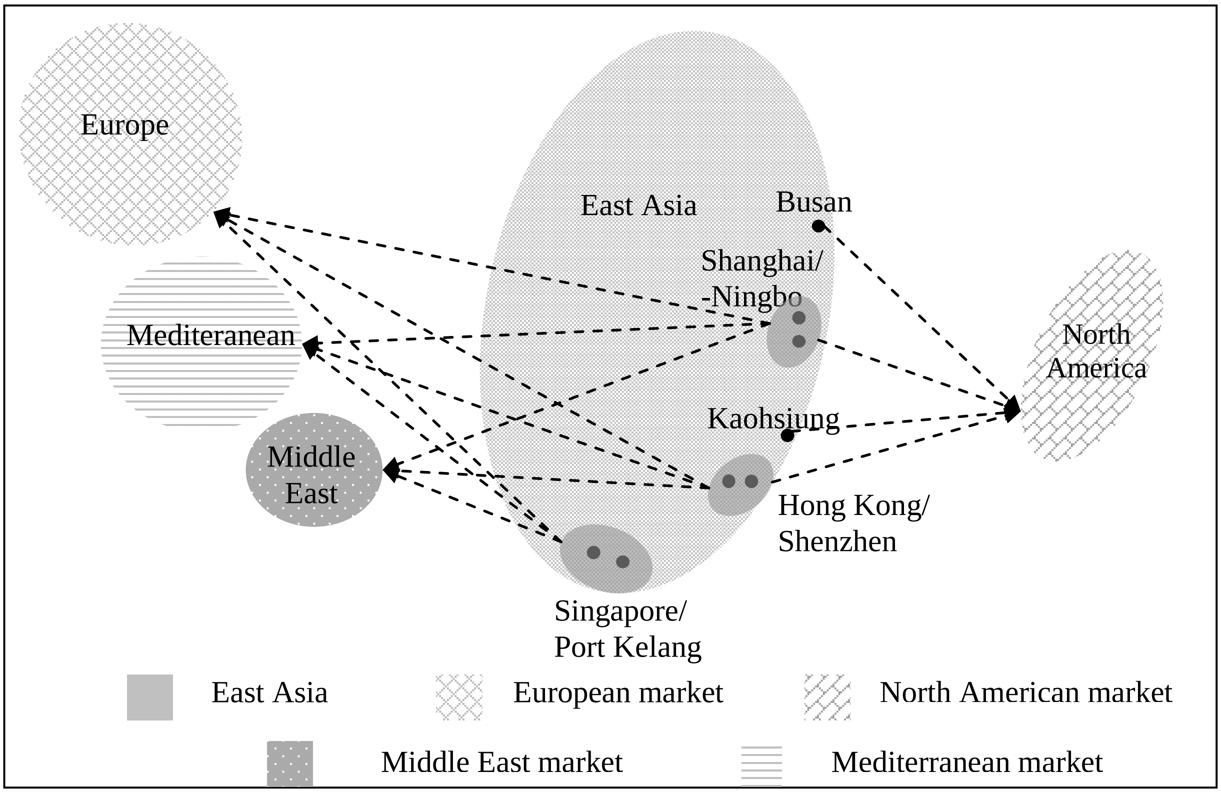

Source: Computed with UCINET

**Figure 4: Sample network configuration with Multiple Linkage Analysis (MLA)**



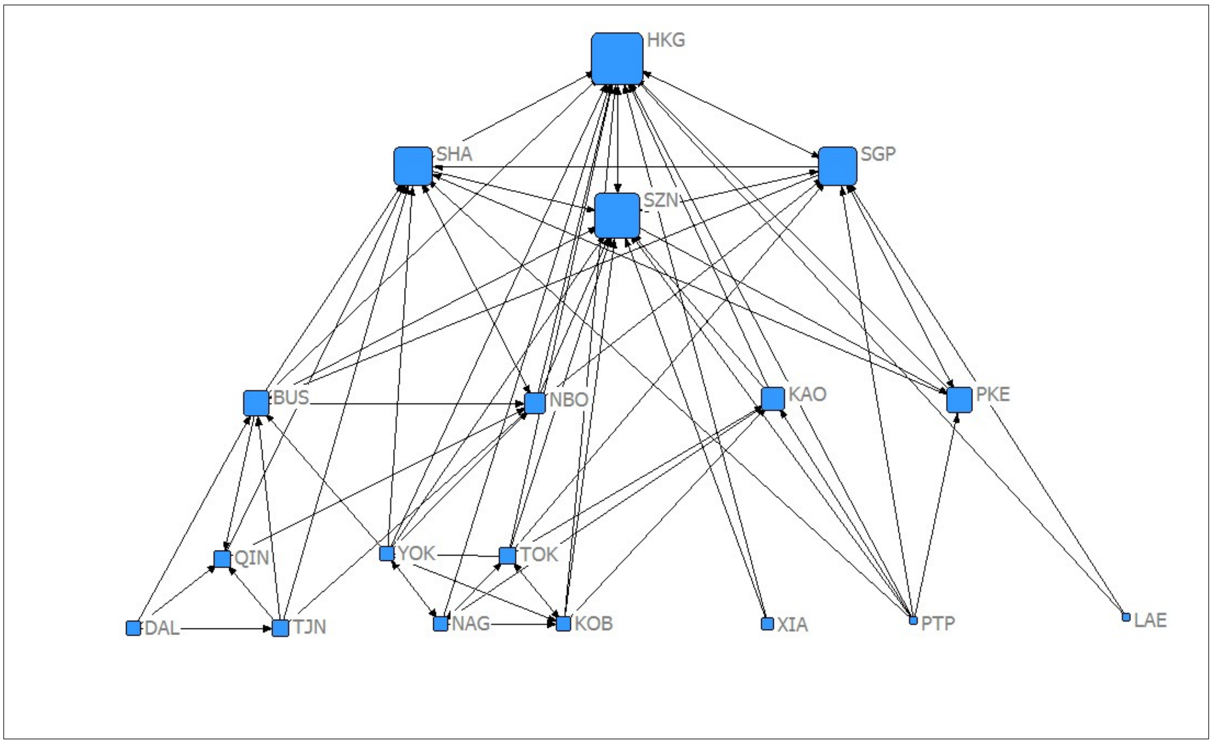

Source: Computed with UCINET

**Figure 5: The distribution of *significant* outflows in intercontinental transportation**




Source: drawn by authors

**Figure 6: Hierarchical illustration of significant flow movements in East Asia**




Source: drawn by authors