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Article

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Original Article

ASEAN logistics network model and algorithm

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ABSTRACT

Reasonable layout of logistics centers in the ASEAN countries has important practical significance for improving logistics network efficiency and reducing logistics transportation costs. This paper based on the current status of the ASEAN logistics network and the characteristics of the hub-and-spoke network, taking the minimum total cost as the optimization goal, establishing the central location model, and the design self-adaptive genetic algorithms to solve it. Therefore, the number of central nodes in the ASEAN logistics network has been determined, the radiation range between nodes, and route allocation. The results indicate that the ASEAN network layout model is a hub-and-spoke logistics network. With Singapore as the logistic center hub node. Jakarta logistics development belt will form the main radiating logistics demand cities of Kuching and Ho Chi Minh city. Kuala Lumpur logistics development belt's main radiating logistics demand cities will be East Kalimantan and Da Nang city. Chon Buri logistics development belt mainly radiates the cities of Phnom Penh and Riau city. Bangkok logistics development belt mainly radiates the cities of Hanoi, Vientiane, and Yangon city.

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1. Introduction

In recent years, along with the continued growth of international trade in the ASEAN region, increasing the volume of goods exchange in the ASEAN region has put pressure on the ASEAN regional logistics network. Therefore, improving the ASEAN logistics network facilities, enhancing the efficiency of the ASEAN logistics network, and reducing logistics costs have become an important part of the development of the region. ASEAN regional logistics network is a spatial organization of ASEAN regional logistics economic activities formed by a combination of logistics nodes and logistics routes. Take the central city as the hub node and radiate the network structure of surrounding cities.

In most of the studies in the hub location mainly focus on two aspects: one is the location and optimization of hub nodes (Alumur, Kara, & Karasan, 2012; Gelareh & Nickel, 2011); the other is the design and optimization of logistics networks (Bowen, 2012; Ming-Jun & Yan-Ling, 2012), it mainly includes a multimodal transport logistics network (Meng & Wang, 2011), postal logistics network (Lee & Moon, 2014), and port logistics network (Dai, Yang, & Li, 2018; Nguyen & Zhang, 2017). However, there is very little research

on mixed central logistics networks. Most research on the focal logistics network is qualitative research and very few studies use mathematical models to study the selection of central nodes. In this paper, starting from the characteristics of a hub-and-spoke network, with the aim of minimizing logistics costs, has established the node location model for the ASEAN logistics network, to determine the number of hub nodes and the distribution of routes. It has important theoretical and practical significance for the development of the logistics industry in the ASEAN countries.

2. Model building

This study is part of my selection and optimization of the hub nodes in the ASEAN logistics network. In my study, take the 2015 statistical data of 21 cities with the most developed economic, trade, and logistics in the ASEAN region as the research object. Then, established the hub cities and the spoke cities by the principal component analysis method. The results indicate that Singapore, Kuala Lumpur, Bangkok, Jakarta, Klang, and Chon Buri are the hub cities of the ASEAN logistics network. Manila, Ho Chi Minh City, Java, Johor, Kuching, East Kalimantan, Riau, Hanoi, Kuantan, Perak, South Kalimantan, Da Nang, Yangon, Phnom Penh and Vientiane are spoke cities of the ASEAN logistics network (Nguyen, 2018). In this paper, we establish the ASEAN network layout model as a hybrid hub-and-spoke logistics network. With the goal of minimizing cost, study the

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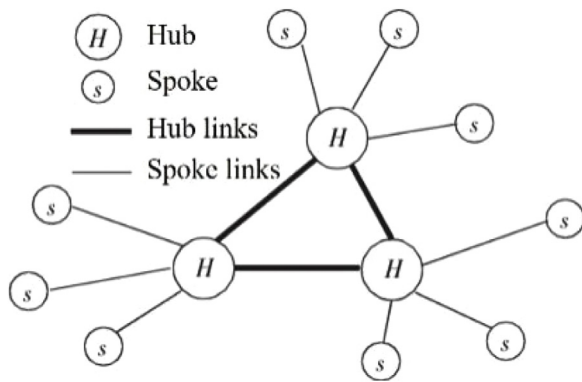


Fig. 1. Hub-and-spoke logistics network.

node location problem of the ASEAN logistics network to determine the number of hub nodes and route allocation.

2.1. Problem formulation

The hub-spoke logistics network is composed of hub nodes, spoke nodes, hub links and spoke links in Fig. 1.

The spoke node in the network interacts with one or more hub nodes. The cargo flow of spoke nodes is first collected to the hub node, and then the hub node conducts consolidation based on the destination site.

ASEAN countries have differences in economic development, transportation infrastructure, logistics, culture, and politics. Therefore, to build an ASEAN logistics network, the nodes in the logistics network must be at different levels. The study uses the principal component analysis method to determine the node level, the hub cities, and spoke cities of ASEAN (Nguyen, 2018) (Fig. 2).

In this paper, the node optimization of ASEAN logistics network is established mainly reflects two aspects: The first is the location and number of ASEAN logistics hub nodes. The second is the distribution of routes.

The core of ASEAN logistics network optimization is to minimize the total costs, that is, the problem of path selection between nodes and the problem of flow distribution between nodes.

Assume that every node i in the ASEAN network sends q_{ij} goods to node j . In the network, the logistics flow from the origination point to the destination point may be sent directly, or some nodes may be selected as hub nodes, but the logistics flow from the origination point to the destination point is collected and distributed through the hub nodes.

Due to the availability of data, it is assumed that the freight volume between ASEAN countries is mainly water transportation. And road transportation and water transportation are the main modes of transportation in various countries. Therefore, only water transportation and road transportation are considered in the model.

2.2. Model assumptions and model parameters

2.2.1. Model assumptions

In order to facilitate model construction and calculation, we give some assumptions as follows:

The ASEAN regional logistics network is a hybrid hub-and-spoke network. Among them, the 6 known hub nodes are fixed and known, candidate hub nodes, and the other nodes are spoke nodes;

The mode of transportation between nodes in the hub nodes is water transportation. The transportation modes between spoke nodes, hub nodes and spoke nodes are road and water transportation.

The freight volume and unit transportation cost between nodes in the ASEAN logistics network are known, and the two-way freight flow between nodes;

There are three options for each OD (Originations - Destinations): it can be directly transported, transit through one hub node, and transit through two hub nodes, but the transportation path can only pass through two hub nodes at most;

This paper establishes a model for the optimal total transportation cost of the ASEAN network. Due to the large construction cost, the construction cost is not considered for the time being.

2.2.2. Model parameters

The following sets and indexes are used to define the parameters and variables of the model:

- N is the set of hub nodes and spoke nodes;
- P is the set of candidate hub nodes in the network;
- p is the number of hub nodes in the network;
- Z is the total transportation cost of the network;
- T is the collection of transportation modes between hub nodes and spoke nodes;

$t \in T, T = \{1, 2\}$, $t = 1$ for road transport, $t = 2$ for water transportation;

U_k is the logistics processing capability of hub node k ;

q_{ij} is the cargo flow from node i to node j ;

δ is the discount coefficient of transportation cost between hub and hub node;

c_{ij} is the unit traffic transportation cost from node i to node j , that is a cost of direct transportation;

c_{ilj} is the unit traffic transportation cost from node i to node j through hub node l ; the flow path is: $i \rightarrow l \rightarrow j$, and $c_{ilj} = c_{il}^t + c_{lj}^t (i, j \in N, l \in P, t \in T)$;

c_{ilmkj} is the unit traffic transportation cost of node i to node j through hub nodes k and m ; the flow path is: $i \rightarrow k \rightarrow m \rightarrow j$,

$$c_{ilmkj}^t = c_{ik}^t + \delta c_{km} + c_{mj}^t (i, j \in N, k, m \in P, t \in T)$$

$$O_i = \sum_{i \in N} q_{ij} \text{ is the logistics originations of node } i;$$

$$D_i = \sum_{j \in N} q_{ji} \text{ is the logistics destinations of node } j;$$

$$x_{ij} = \begin{cases} 1, & \text{direct transportation from node } i \text{ to node } j \\ 0, & \text{otherwise} \end{cases};$$

$$x_{ilj} = \begin{cases} 1, & \text{node } i \text{ to node } j \text{ selects hub node } l \text{ for transit} \\ 0, & \text{otherwise} \end{cases};$$

$$x_{ilmkj} = \begin{cases} 1, & \text{node } i \text{ to node } j \text{ selects hub nodes } k \text{ and } m \text{ for transit} \\ 0, & \text{otherwise} \end{cases};$$

$$y_k = \begin{cases} 1, & \text{node } k \text{ can be selected as a hub node} \\ 0, & \text{otherwise} \end{cases};$$

$$z_{ij}^t = \begin{cases} 1, & \text{from node } i \text{ to node } j \text{ use transportation mode } t \\ 0, & \text{otherwise} \end{cases}$$

2.2.3. Model building

Minimize the total cost (Z) which is described as:

$$\min Z = \sum_{i,j \in N} x_{ij} q_{ij} c_{ij} + \sum_{i,j \in N, l \in P} x_{ilj} q_{ij} c_{ilj} + \sum_{i,j, \in N, k, m \in P} x_{ilmkj} q_{ij} c_{ilmkj} \quad (1)$$



Fig. 2. Spatial layout of ASEAN logistics nodes.

subject to:

$$\sum_{k \in P} y_k = P \tag{2}$$

$$c_{ij} = \sum_{t \in T} c_{il}^t z_{il}^t + \sum_{t \in T} c_{lj}^t z_{lj}^t, (i, j \in N, l \in P, t \in T) \tag{3}$$

$$c_{ikmj} = \sum_{t \in T} c_{ik}^t z_{ik}^t + \delta c_{km} + \sum_{t \in T} c_{mj}^t z_{mj}^t, (i, j \in N, k, m \in P, t \in T) \tag{4}$$

$$\sum_{t \in T} z_{ij}^t = 1 \forall i, j \in N \tag{5}$$

$$\sum_{i, j \in N, k, m \in P} (q_{ij} c_{ikmj} + q_{ji} c_{jmki}) = (O_i + D_i) x_{ikmj} \tag{6}$$

$$\sum_{i, j \in N, k, m \in P} (O_i + D_i) x_{ikmj} \leq U_k \tag{7}$$

$$x_{ij} + \sum_{l \in P} x_{ilj} + \sum_{k \in P} \sum_{m \in P} x_{ikmj} = 1 \forall i, j \in N \tag{8}$$

$$x_{ilj} \leq y_l \forall i, j \in N, l \in P \tag{9}$$

$$x_{ikmj} \leq y_k \forall i, j \in N, k, m \in P \tag{10}$$

$$x_{ikmj} \leq y_m \forall i, j \in N, k, m \in P \tag{11}$$

$$x_{ij}, x_{ilj}, x_{ikmj}, y_k, z_{ij}^t \in \{0, 1\}, \forall i, j \in N, l, k, m \in P, t \in T \tag{12}$$

Objective function (1) minimizes the total transportation cost of ASEAN logistics network, and it consists of three parts: The first item indicates the logistics cost of using direct transportation; the second item indicates the logistics costs through one hub node; the third item indicates the logistics costs through two hub nodes;

Constraint (2) indicates the total number of selected hub nodes; (3) and (4) indicate the establishment conditions of passing through a single hub node and double hub nodes; (5) to ensure that only one transportation mode can be selected between spoke nodes, hub nodes and spoke nodes; (6) represents the conservation of node flow; (7) indicates the processing capacity constraint of the hub node; (8) reflects that the three schemes of transportation route allocation are direct transportation, single-hub transportation, and double-hub transportation. Constraints (9), (10), (11) indicate the connection constraints between spoke nodes and hub nodes; (12) indicates the constraints of decision variables, ensuring that their value can only be 0 or 1.

3. Algorithm design

This study contains optimization problems such as pivot point location and path allocation. The model constructed is an NP-hard problem. It is difficult to find a solution to the problem with traditional algorithms, and it is necessary to design a suitable heuristic algorithm to find a better solution to the problem. Genetic algorithm has achieved good results in combination optimization problems such as hub selection, route allocation, and network opti-

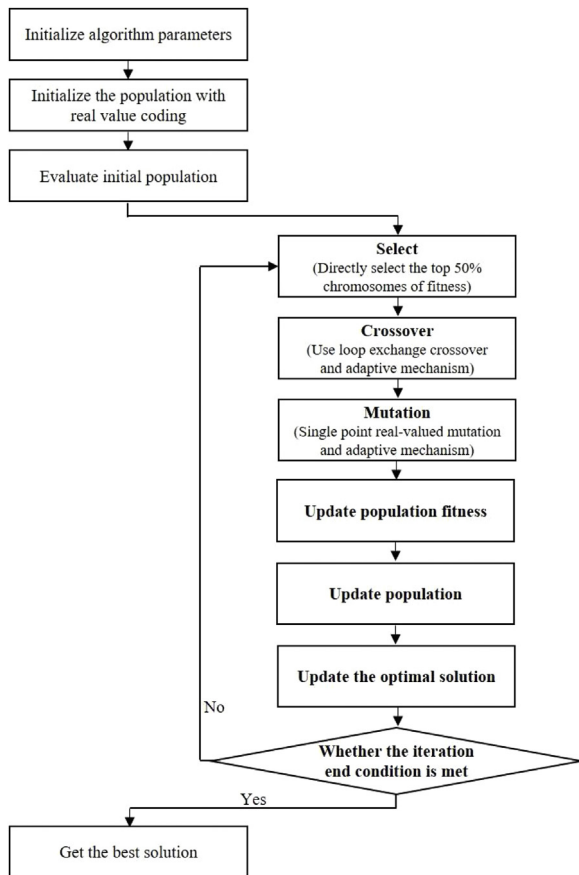


Fig. 3. Flowchart of the Genetic Algorithm.

mization. Therefore, we proposed self-adaptive genetic algorithm for solving the node location problem of the ASEAN logistics network. Fig. 3 demonstrates the steps of this approach.

The steps of genetic algorithm mainly include chromosome encoding and decoding, fitness calculation, selection, crossover, mutation, population update and other operations.

This study will individually improve these operations to adapt to the characteristics of the problem.

1 Chromosome encoding and decoding

In this article, chromosomes use real-valued coding. From the determined num.h candidate hub nodes, the optimal hub node plan and the optimal transportation route between each node are selected.

Each chromosome is a vector composed of random numbers in 1-num.h and the length is the number of nodes; each chromosome bit corresponds to a node, and the number of this chromosome bit corresponds to the pivot point covering this node; which is selected as the pivot point corresponding to the node of is invalid. Assuming there are 10 nodes, select the pivot node from the nodes numbered 1–4, the length of the generated chromosome is 10, the number of each chromosome bit is a random number from 1 to 4. For example, 1424314132 is a chromosome. Since there are 1, 2, 3, and 4 in chromosomes. Therefore, the first 4 bits of the chromosome are invalid bits, and the first 4 bits are not considered in the calculation. Positions 5–10 of chromosomes correspond to the pivot points corresponding to the nodes numbered 5–10. However, if the pivot point selection changes to three points 1, 3, and 4 during the calculation process, the node corresponding to the number of the second chromosome bit is converted from the pivot point to the node, and

the corresponding number is no longer invalid data. Encoding in this way is to dynamically determine the number of pivot points during the calculation process, and at the same time, a fixed number of pivot points can be set for calculation. This article selects num.h = 6; in the following tests, a fixed number of pivot points will be set for testing.

The decoding process is divided into two steps: The first step is to merge the nodes corresponding to the same pivot point into a set. Then, according to the principle of the least comprehensive cost, determine the path of the pivot point between the two nodes. Similarly, use the example in the previous paragraph for explanation. First, divide the node set corresponding to the candidate pivot points. The nodes corresponding to pivot point 1 are 6, 8 respectively; the node corresponding to pivot point 2 is 10; the nodes corresponding to pivot point 3 are 5 and 9; the node corresponding to pivot point 4 is 7. Then the path between the six nodes 5–10 were calculated. For example, calculate the path between 5 and 10. Compare the path costs in the four cases of 5–10, 5–3–10, 5–2–10 and 5–3–2–10 respectively, and select the path corresponding to the smallest cost as the final path.

2 Fitness function

In this paper, the model solution uses the model objective function as the fitness function of the algorithm, and the fitness corresponding to the infeasible solution is set to infinity.

3 Selection operator

This paper directly selects the chromosomes with fitness values in the top 50% of the population, and adopts the strategy of retaining elites, so that individuals with better fitness values have a greater probability of entering the next generation.

4 Crossover operator

This paper adopts the sub-path exchange crossover operator to prevent premature maturity. Using the adaptive method, when the individual fitness is less than or equal to the average fitness of the population, the crossover probability is pc1, otherwise it is pc2 (pc1 < pc2).

5 Mutation operator

The adaptive single-point real-valued mutation is adopted, and the adaptive method is also adopted. When the individual fitness is less than or equal to the average fitness of the population, the mutation probability is pm1, otherwise it is pm2 (pc1 < pc2).

6 Population update

In this section, two strategies will be used to update the population. In the first type, when an infeasible solution is obtained in crossover and mutation, the poorer chromosome in the parent is replaced with a new chromosome. The second is to update the last 10% of the chromosomes in the chromosome population with new chromosomes.

4. Results and discussion

Through MATLAB R2014a software runs calculations to solve the ASEAN logistics network optimization model. In order to make the results more scientific and effective, the number of iterations in this paper is 500, the crossover probability is 0.9, and the mutation

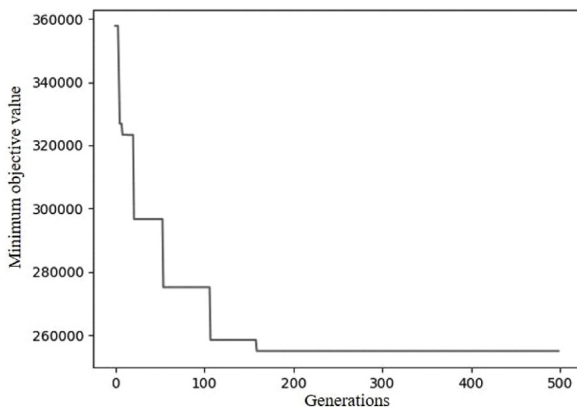


Fig. 4. Evolution curves of genetic algorithm.

Table 1
Optimization results of ASEAN logistics network hub nodes.

| Total cost | Number of hub | Hub | Number of spoke |
|-------------------|---------------|--|-----------------|
| 2.36 trillion USD | 5 | Singapore, Kuala Lumpur, Bangkok, Jakarta, Chon Buri | 16 |

probability is 0.01. The objective function value is 2.36 trillion US dollars, and the total cost is the optimal result.

Fig. 4 shows the best fitness values at each generation as a function of the number of generations, and the results of the location of the hub node are shown in Table 1.

It can be seen from Table 1 that the optimal value of the total cost of ASEAN logistics network is 2.36 trillion USD. The ASEAN network is reasonably configured as 5 hub cities and 16 spoke cities. The main selected logistics hub cities are: Singapore, Kuala Lumpur, Bangkok, Jakarta and Chon Buri city. Spoke cities are: Klang, Perak, Johor, Kuantan, Kuching, Java, Riau, South Kalimantan, East Kalimantan, Hanoi, Da Nang, Ho Chi Minh City, Manila, Yangon, Phnom Penh and Vientiane city.

ASEAN logistics network is evenly distributed with 5 hub cities, covering the entire ASEAN logistics network. Among them, Singapore has geographical advantages, complete infrastructure,

economic development ranks first in the ASEAN region, and strong comprehensive logistics services. It is a first-level logistics hub city in the ASEAN region. Then, Kuala Lumpur, Bangkok, Chon Buri, and Jakarta city as a transit bridge for the logistics exchange volume in the ASEAN region. They have an important role in ASEAN and are the secondary logistics hub cities in the ASEAN region. Klang, Perak, Johor, Kuantan, Kuching, Java, Riau, South Kalimantan, East Kalimantan cities, Hanoi, Da Nang, Ho Chi Minh City, Manila, Yangon, Phnom Penh, and Vientiane city are economic and logistics infrastructure construction belongs to the development stage and is a third-level logistics spoke cities in the ASEAN region.

The five hub cities in the ASEAN region have different locations, different logistics demand, so their radiation ranges are also different. Table 2 shows the route allocation results of ASEAN hub node cities and spoke cities.

According to the above results, the ASEAN regional logistics network is based on Singapore city as the hub node center. The hub cities around Jakarta city in Indonesia, Kuala Lumpur city in Malaysia, Bangkok, and Chon Buri city in Thailand is attractive to other spoke cities (Fig. 5).

5. Conclusions

This research considering the current situation of the ASEAN regional logistics network, the analysis of 21 cities' logistics freight volume, and combining the characteristics of the hub-and-spoke network structure. Then, establishes a model for the location of the hub node of the ASEAN logistics network and designs an improved genetic algorithm to solve it. Through the calculation results, the number of hub cities, the reasonable configuration of hub nodes, and the radiation range of hub nodes are determined in the ASEAN logistics network. And proved the feasibility of the ASEAN logistics network optimization plan. ASEAN regional logistics network is based on Singapore city as the hub node center. The main radiating logistics demand cities of Jakarta logistics development belt are Ho Chi Minh, Kuching, and Java city; Kuala Lumpur logistics development belt's main radiating logistics demand cities are East Kalimantan, Kuantan, and Da Nang city; Chon Buri logistics development belt mainly radiates Phnom Penh and Riau city; Bangkok logistics development belt mainly radiates Hanoi, Vientiane, and Yangon cities.

Table 2
Route allocation results of ASEAN logistics network.

| Logistics node | Singapore | Kuala Lumpur | Bangkok | Jakarta | Chonburi |
|---------------------------|-----------|--------------|---------|---------|----------|
| Singapore | 0 | 0 | 0 | 0 | 0 |
| Kuala Lumpur | 0 | 0 | 0 | 0 | 0 |
| Bangkok | 0 | 0 | 0 | 0 | 0 |
| Jakarta | 0 | 0 | 0 | 0 | 0 |
| Chon Buri | 0 | 0 | 0 | 0 | 0 |
| Klang | 1 | 0 | 0 | 0 | 0 |
| Manila | 1 | 0 | 0 | 0 | 0 |
| Ho Chi Minh | 0 | 0 | 0 | 1 | 0 |
| Java | 0 | 0 | 0 | 1 | 0 |
| Johor | 1 | 0 | 0 | 0 | 0 |
| Kuching | 0 | 0 | 0 | 1 | 0 |
| East Kalimantan | 0 | 1 | 0 | 0 | 0 |
| Riau | 0 | 0 | 0 | 0 | 1 |
| Hanoi | 0 | 0 | 1 | 0 | 0 |
| Kuantan | 0 | 1 | 0 | 0 | 0 |
| Perak | 1 | 0 | 0 | 0 | 0 |
| South Kalimantan | 1 | 0 | 0 | 0 | 0 |
| Da Nang | 0 | 1 | 0 | 0 | 0 |
| Yangon | 0 | 0 | 1 | 0 | 0 |
| Phnom Penh | 0 | 0 | 0 | 0 | 1 |
| Vieng Chan | 0 | 0 | 1 | 0 | 0 |
| The amount (100,000 tons) | 27,848 | 6272 | 4117 | 23,147 | 1055 |

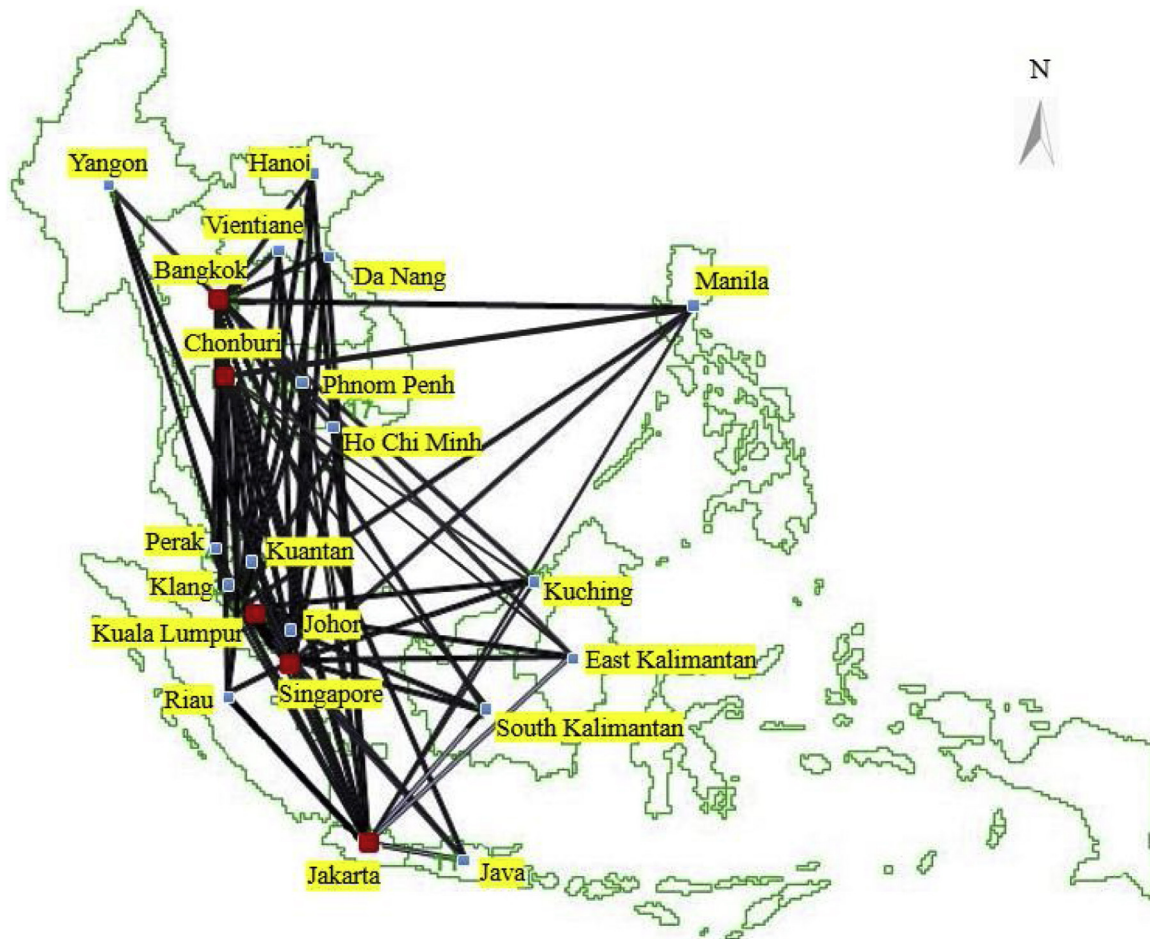


Fig. 5. ASEAN logistics network layout results.

Conflict of interest

The authors declare that they have no competing interest.

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