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Transportation network analysis and hub identification for exporting agricultural products

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A B S T R A C T

Agriculture products are one of the main income sources of developing countries. This study analyzes the road transport system (network) to reveal the network's structural properties and identifies hubs that consolidate agricultural products to export to China via the China-Laos railway. Analysis of 20 provinces in the Northeast of Thailand has found that the network has 340 districts connected by 1,015 transport routes. The network is sparse, in which all districts cannot be connected to each other. The network has low connectivity efficiency but has high intra-connectivity among districts in the same province. In addition, the network has a modularity structure that can develop the communities. Hubs consolidating agricultural products of the region are Na Khu, Kuchinaria, Mueng Chiyaphum, Nam Phong, Na Wa, Mueang Mukdahan, Prasat and Rasi Salai. The findings of the study draw implications for the government, sector and exporters to design and improve their operations and services.

1. Introduction

Agriculture products are one of the main income sources of some countries, especially developing countries. Agriculture products have been together with the Thai people for a long time, and are a source of income for the community, farmers, families and even the country. Thailand has used areas to produce agricultural products around 58,993,564 acres. Among these, areas used to plant rice are 3,449,916.20 acres, which is the highest proportion, followed by fruits 3,449,916.21 acres and field crops 12,147,837.55 acres. 7,490,110 households are working in agriculture. Each family can generate an income per family of 370,049 baht per year (Office of Agricultural Economics, 2019). This means revenue from agriculture is one of the main sectors that contributes to the growth of Thailand's economy. Exporting agricultural products contributes to the Thai economy. In 2021, the value of agricultural exports in Thailand was 1,011,719 million baht (Office of Agricultural Economics, 2023). Free trade agreements are the key to supporting Thai agricultural products' high competitiveness in the global market. The top 10 countries importing agricultural products from Thailand are China, Japan, the United States of America, Malaysia, Vietnam, Cambodia, Myanmar, India, South Korea and Indonesia, respectively. Thailand exported agricultural products, especially agricultural products with Thai phytosanitary certificates, more than 23.7 million tons, worth more than 536 billion baht. Fresh fruits ranked first with the highest exporting value, followed by rice, rubber and its products (TCIJ, 2023). Thailand also exports agricultural products to the ASEAN countries, with a high trade value. This is because Thailand gets the advantage of being an ASEAN member in terms of free trade (Jetschke, 2012). The export trade value to the ASEAN countries was 121,164 million baht in 2020(International Trade Negotiation Information Center, 2021). The export value of agricultural products to China in 2021 was 443,429 million baht, which was much larger than that of all ASEAN countries (Office of Agricultural Economics, 2023). Thailand's agricultural products are exported the most to China, with the export value of agricultural products of 443,429 million baht (Office of Agricultural Economics, 2023). This is much higher than that of all ASEAN countries. That is China is the most important market for exporting Thai agricultural products. To support exporting, it is necessary to have an efficient export system. Previously, most agricultural products were exported to China via ships (waterway) because it has the lowest cost (Coyle et al., 2015). However, this transport mode takes a long time to deliver

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products. For example, a ship delivers goods from Laem Chabang (Thailand) to Shanghai (China), taking time for six days and three hours. This makes the products damaged or rotten before arriving at a destination. This mode is suitable for areas close to the ocean. Therefore, it is necessary to find a better transportation mode to support exporting Thai agricultural products, especially supply areas far from seaports, such as Northeast Thailand.

A railway is another type of transportation mode with a low transportation cost and can carry a large number of goods at once. Railway transportation is used to deliver goods land-based and delivers goods mostly between cities in a country, but rarely across countries because of the topography limitation (Huisman et al., 2005). In December 2021, the first bullet train (the China–Laos railway) was opened to deliver passengers from China to Laos, with a distance of 1,035 kilometres taking time 4 hours and 20 minutes (ZHANG et al., 2020, Rowedder, 2020; Cho et al., 2012). This is a good opportunity for Thailand to export more products to China and Laos. Moreover, about 10 million Chinese tourists visit Thailand each year. A high-speed train can boost Thai tourism from Chinese tourists, increasing by at least 50%. Additionally, Thai people can also travel to China more easily (Kromadit, 2021). Thailand will benefit from the China-Laos railway in terms of local economic growth, especially in the provinces in the Northeast. The industrial sector is alert to prepare investment plans to support business growth. Some sectors have started building warehouses, logistics systems or a logistics business, although the current connection in various systems has not been completed 100%. Although the China-Laos railway is not directly connected to Thailand, it is still convenient for travel and transportation. This leads to having more opportunities to welcome Chinese tourists and export goods to China through Laos (Kromadit, 2021). Thai people, especially Northeast people, will benefit greatly. Northeast people are mostly farmers who produce agricultural products main source of Thai income. However, the Northeast is far from seaports which makes it difficult to export the products. Therefore, exporting products to China through Laos via China–Laos railway is a better choice since it takes a shorter time and has a low cost. The government should take this advantage to support farmers and exporters. To do so, the government should improve the transport system to support this. The government may also need to build transportation hubs or terminals to be a consolidation point. This issue must be urgently addressed. Therefore, the Thai transport system needs to be investigated in terms of the connection between districts (locations) in 20 provinces in the Northeast as well as identifying transport hubs. This will be used to improve the system or identify potential hubs consolidating the products. Therefore, this study analyzes the Thai transport system and identifies hubs as central points to consolidate agricultural products to export to China via the China-Laos railway.

2. Literature review

A network is used to present a transport system, representing a transportation's flow and structure. The design and evolution of a network are physically limited. This leads to it belonging to many categories of a spatial network (Rodrigue and Ducruet, 2020). A transport network is a result of a trade-off between the goal of linking many places and the constraints of cost and infrastructure development (Lecheval et al., 2021). A network presents a region's territorial structure, encompassing economic relationships (Larson & Starr, 1993). It is rarely planned, depending on developments such as conditions and investment (Melody, 2003). The popularity of the network and its transport mode can be made by providing a region's accessibility and mobility, technical improvements or trade corridors. This also establishes the network (Rodrigue, 2020). A complex network is more valuable than a simple network. This is because a complex network provides more options to connect destinations (Metcalfe, 2013). Therefore, the complexity of a network is relevant to economic development. The structure of a transport network consists of nodes, edges, corridors, hubs and flows (Hesse & Rodrigue, 2004). A network's type is identified according to its properties. A regular network has nodes with the same number of links, like a random network that is generated randomly. A regular network tends to be linked to high levels of spatial organization, but a random network is likely to be linked with development opportunities (Erdős and Rényi, 1960). A small-world network has dense connections among its close neighbors but has fewer connections among distant neighbors. It is vulnerable to failure around large hubs (Watts & Strogatz, 1998). A scale-free network has a strong hierarchical structure, with many nodes having low connectivity and fewer nodes having high connectivity. The evolution of this network happens through the dynamics of preferential attachment. That is new nodes added to the network are connected to high connectivity nodes (Barabási & Bonabeau, 2003). It is challenging to analyze the interdependency among transport networks with different structures and natures. Some important issues are related to inter-network relations, such as coevolution, complementarity, interoperability and vulnerability (Vespignani, 2010). A transport network's efficiency is reflected by the flow's ability to meet all constraints. Network analysis and graph theory can be used to measure efficiency (Yazdani & Jeffrey, 2011, Zhang et al., 2013). The efficiency depends on its nodes and edges. Besides flow's ability, the efficiency must consider the relationship between costs and revenue of operating the network (Rodrigue, 2020). This reflects that the network's structure is likely to be affected by transportation costs (Brueckner and Zhang, 2001, Jeong et al., 2007). The network's resilience also influences the network's efficiency. Reflecting the ability to support disruptions while maintaining service and connectivity (Jeong et al., 2007).

The hubs of transportation are a common element structure of transport networks. In the transport system, a hub in a center location with many connections. A hub plays a critical role in handling a substantial amount of traffic and links the network's elements (Rodrigue and Ducruet, 2020). A hub also reflects the focal economic point of the network and promotes international trade and regional economic development (Wan et al., 2021; Kanrak and Nguyen, 2022). In a network perspective, a hub of the network can be defined using centrality measures (Wan et al., 2021; Kanrak et al., 2023).

Research in transport networks started in the 1960s. One of the early studies, O'Sullivan (1968) investigated the interaction between the spatial structure of transport networks and the geographical structure of the Irish economy using graph theory. In the 2000s, network properties received more attention, which was analyzed using complex network analysis, and social network analysis (Sienkiewicz & Hołyst, 2005). More recently, studies have been analyzed using various network measures and models to study networks from different network perspectives, such as Ducruet et al. (2010), Niavis and Tsiotas (2018), Jeon et al. (2019), Kanrak and Nguyen (2021). Wan et al., 2021 and Kanrak et al., 2023. Network analysis can be used to study network structure, evolution, stability and dynamics, as well as the relationship between nodes in a network. Many models have been used to analyze networks, such as random graphs (Erdős and Rényi, 1960), stochastic block model (Holland et al., 1983) and a small-world network (Watts & Strogatz, 1998). These models have been widely used to analyze empirical transport networks, such as Soh et al. (2010), Sapre (2011), Couto et al. (2015), Chen et al. (2020) and Kanrak and Nguyen (2022). Studies on road transport networks have focused on routing design and scheduling using optimization models and algorithms, such as Feng and Yang (2009), Polimeni and Vitetta (2011), Zakharov and Krylatov (2015), Villarreal et al. (2016) and Aravindhan et al. (2021). The lack of research studies road transportation from a network structure perspective to design the transport system and identify hubs. From the above literature, network analysis, particularly complex network analysis, has been widely used in transport networks, especially maritime and air transport networks to study network connectivity and relationships between ports. Most studies focus on investigating networks at the global level, limited research analyses road transport networks at the regional level. Additionally, the lack of research identifies transportation hubs from the network aspect. These gaps will be addressed in this research project. The present study will analyse the transport network at the regional level by investigating its structure, characteristics and properties as well as identifying transportation hubs to support Thai export via the China- Laos railway. This study will also present the network that connects Thai locations and Laos, Vietnam and China to provide an important strategy for expanding the export market.

3. Research methodology

In this study, the Thai transport system (network) is considered an undirected network where every pair of districts is connected. Let *G(V, E)* be the transport network, where *V* is the set of districts (nodes); $V = \{v_i = 1,2,\ldots,n\}$, $n = |V|$, and *E* is the set of transport routes as edges or links; $E = \{e_i = 1,2,\ldots,m\}$, $m = |E|$. The network is presented by an adjacency matrix A_{nxn} with element $a_{ij} = 1$ when district *i* and district *j* are connected, and $a_{ij} = 0$ otherwise. Two districts are defined to be neighbors if there is a link between them. Given the focus on the topology, the intensity of transportation movement between districts (weight of a link) is not considered. Table 1 presents the measures of social network analysis used in this study. Four measures are used to study the structural properties of the transport network including network density, average path length, diameter, average clustering coefficient and modularity. Three centrality measures are used to analyze the properties and roles that districts play in the network. The centrality measure is also used to identify the hubs of the network, which consolidate agricultural products of Northeast Thailand for export to China via the China-Laos railway (Wang et al., 2011).

Table 1
Statistical measures of SNA for analyzing the network

	Measure	Equation	Description
Network level	Network density	$\rho(G) = \frac{2m(G)}{n(n-1)}$	The proportion of the number of connections to the possible number of connections.
	Average path length	$L = \frac{1}{n(n-1)} \sum_{i \neq j}^{n} d(i, j)$	The average number of steps along the shortest paths for possible pairs of nodes.
	Diameter	$\delta = \max_{ij} \{d(i, j)\}$	The maximum length of any shortest path between nodes.
	Average clustering coefficient	$C = \frac{1}{n} \sum_{i=1}^{n} \frac{E_i}{k_i(k_i - 1)/2}$	The fraction of the number of connections between the nodes within its neighbors and the possible number of connections that exist between them
	Modularity	$Q = \frac{\sum_{i,j} [A_{ij} - P_{ij}] \cdot \delta(g_i, g_j)}{2m}$	The fraction of links within communities and the expected proportion of all links placed randomly
District level	Degree Centrality	$C_D(i) = \sum_{j=1}^{n} a_{ij}$	The sum of the connections that a node has.
	Betweenness centrality	$C_B(i) = \sum_{s \neq i \neq t} \frac{\sigma_{s,t}(i)}{\sigma_{s,t}}$	The sum of the proportion of the total number of the shortest paths from node *s* to node *t* passing through node *i* to the possible number of shortest paths from node *s* to node *t*.
	Closeness centrality	$C_C(i) = \frac{n-1}{\sum_{j \neq i} d(i,j)}$	The inverse of the shortest paths from a given node to all others.

Let *m* is the number of links (connections) the network has,
n is the number of nodes,
d(i,j) is the shortest path from nodes *i* to *j*,
k_i is the number of links that node *i* has,
a_{ij} is 1 if a connection between nodes *i* and *j* exists, 0 otherwise,
g_i is the community of node i,

$[A_{ij}-P_{ij}]$ is a difference between the actual minuses that the expected number of links falling between a pair of nodes,
$\delta(g_i, g_j)$ is the indicator function returning 1 when $g_i = g_j$, $\sigma_{s,t}(i)$ is the number of shortest paths from nodes s to t passing through node i, and
$\sigma_{s,t}$ is the total number of shortest paths from nodes s to t.

Network density is used to analyze the network's connectivity level. The average path length and diameter reflect the efficiency of network connectivity. A shorter average path length indicates more efficiency in network connectivity. Likewise, a shorter diameter signifies a more compact network as its nodes are more easily connected (with few steps between them) (Scardoni & Laudanna, 2012). The clustering coefficient is used to analyze the intra-connectivity among districts within the network, expressing the probability of meeting transport connections among neighbors of a district. It is also used as an index of the local transport (neighborhood) connectivity around a district (Tsiotas & Polyzos, 2015). Modularity is used to analyze the strength of the division of the network into subnetworks (communities). Degree centrality is used to analyze the district's connectivity. A district with the highest degree of centrality indicates it has the highest connection. It is therefore defined as an important and popular district in each province. Betweenness centrality reflects the degree to which a district can take an 'intermediary' role and its potential accessibility. A district with the highest degree and between centralities is defined as a hub of the network, which is the point of consolidating agricultural products to export to China via the China-Laos railway. This measure is also used to analyze the spatial structure of the network and identify its regional hubs. It is easier for a district with a higher closeness centrality to reach all the others in the network. In this case, closeness centrality is used to interpret the convenience for trucks as they can deliver the products between one district and others.The above network measures are used to analyze the transport network in the Northeast. The dataset covers the network of 340 districts in 20 provinces in the Northeast of Thailand. This study defined nodes as districts in each province and edges or links as transport routes that connect between districts. This region was chosen since it is near the Lao border and the China-Laos railway. Additionally, it has the largest agricultural area in Thailand compared to other areas Economics (2019). Network analysis is conducted using R statistical software.

4. Result

4.1 Network topological properties

Fig. 1 shows the graph visualization of the road transport network in the Northeast of Thailand. The network consists of 340 districts (nodes) that are connected by 1,015 roads (links).

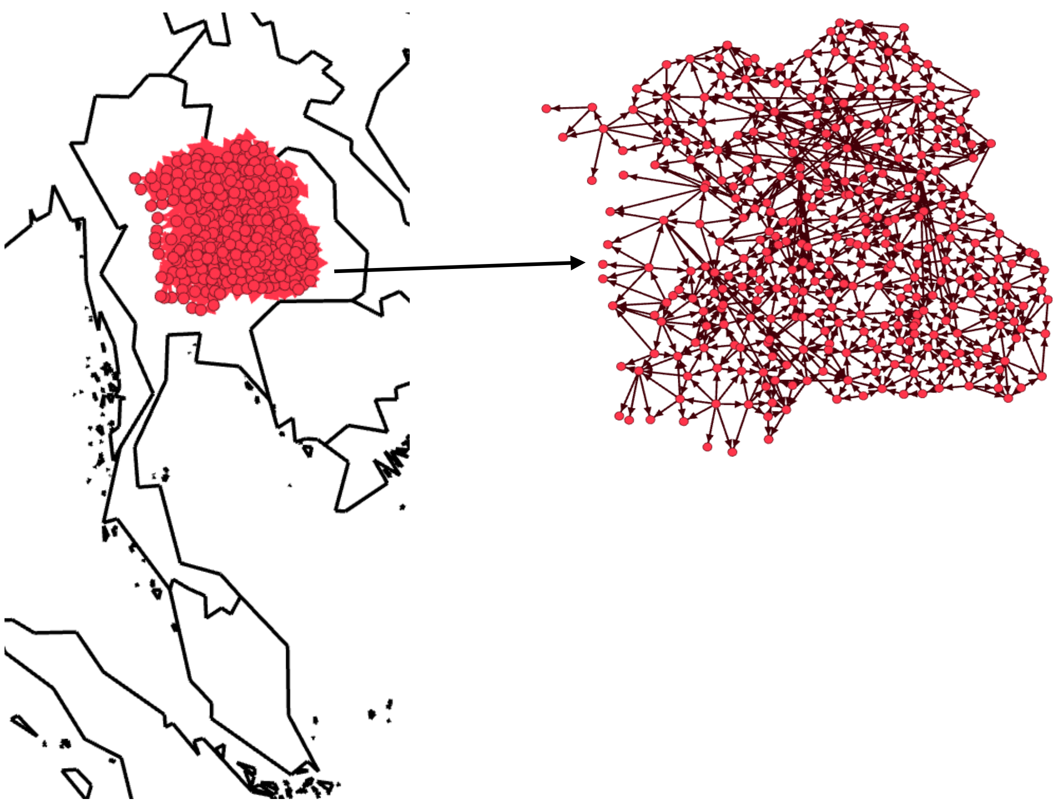

Fig. 1. Graph of the road transportation network in the Southeast of Thailand

Source: Author

Nodes connect to other nodes in the same province and other provinces. The network has a density of 0.0172, which is relatively low, according to the highest value of one. This indicates the possibility that districts can connect to all others. Therefore, the network is sparse in that its nodes are less cohesive since a district cannot connect to all others. This is because of the location limitation of a district that makes it unable to connect to all others. The low density of the network studied also reflects that the transportation of agricultural products can flow difficultly and slowly. This is because transporting the products from one district to one another mostly cannot go directly, it needs to pass others before arriving at a destination district. The network has an average path length of 6.0315, indicating that a district takes at least six connection steps on average to connect to one another in the network. This reflects that the network has a low efficiency of information and mass transport on the network. A low efficiency is also confirmed by the large diameter of the network of 14. This number reflects that the most distant connection between two districts takes 14 connection steps on average. A high diameter also implies that the network is a less-linked network (sparse). The clustering coefficient reflects a connection between the neighbors of a district over the total number of possible links. The network has an average clustering coefficient of 0.3661, which is quite high. That is, districts in the network tend to cluster together, especially districts in the same province. The network has a molarity of 0.71 relatively high. Note that a modularity is larger than 0.4 suggesting that a network has a modular structure (Newman, 2006). Therefore, the network studied has a modularity structure that has a high ability to develop communities. This indicates that the network has dense connections between districts within the same province (communities or clusters) but has sparse connections between districts in other provinces. This corresponds to the high average clustering coefficient mentioned above.

4.2 District properties

Different centrality measures reflect the different properties that districts (nodes) play in the network. Table 2 illustrates the districts with the highest values of degree centrality. Kuchinarai and Na Khu in Kalasin rank first with the highest degree centrality of 12, indicating that they are connected to other 12 districts. Selaphum (Roi Et) and Det Udom (Ubon Ratchathani) rank second with a degree centrality of 11. Nam Phong, Na Wa, Ban Phue and Wang Sam Mo in four provinces rank third with a degree centrality of 10. There are 19 districts in 11 provinces ranking four with a degree centrality of nine. This indicates that the high-degree districts are more central. These districts are the most important and popular in the network since they have high connectivity to others. To be efficient in transportation, it is necessary to avoid potential bottlenecks in high-degree districts. There are 17.65% of districts having a degree centrality of 1-4 degrees, and 64.41% having a degree centrality of 5-8. Only a small proportion of districts have a high degree, higher than 8 degrees. This confirms that the network has a scale-free property.

Table 2
District with a high value of degree centrality

District	Province	Degree centrality	Number of districts
Kuchinarai, Na Khu	Kalasin	12	2
Selaphum, Det Udom	Roi Et, Ubon Ratchathani	11	2
Nam Phong, Na Wa, Ban Phue, Wang Sam Mo	Khon Kaen, Nakhon Phanom, Udon Thani	10	4
Mueang Kalasin, Chum Phae, Mancha Khiri, Nong Song Hong, Phu Khiao, Mueang Chaiyaphum, Khong, Prathai, Rattanaburi, Dan Khun Thot, Mueang Buri Ram, Mueang Maha Sarakham, Wapi Pathum, Rasi Salai, Sawang Daen Din, Prasat, Si Bun Rueang, Ban Dung, Mueang Udon Thani	Kalasin, Khon Kaen, Chaiyaphum, Nakhon Ratchasima, Buri Ram, Maha Sarakham, Si Sa Ket, Sakon Nakhon, Surin, Nong Bua Lam Phu, Udon Thani	9	19

In terms of betweenness centrality, a district with a high between centrality is an intermediate in the network playing a transition of a connection between two districts. Table 3 presents the 15 districts that have a high betweenness centrality. Na Khu ranks first with the highest betweenness centrality, followed by Khao Wong, Ban Khwao, Mueang Chaiyaphum, Pha Khao, Waeng Yai, Kuchinarai, Khuang Nai, Nam Phong, Prasat, Na Wa, Nong Bua Daeng, Rasi Salai, Mueang Mukdahan and Khon San, respectively. That is these districts are intermediates of the network since they have high accessibility. 63.24% of districts have betweenness centrality values between 1-1000. Districts with a betweenness centrality of 1001-2000 account for 15.88%, while 5.88% of districts have a betweenness centrality of 2001-3000. These reflect that these districts play less intermediary roles in the network. Only 5.29% of districts have a betweenness centrality larger than 3000, playing a more intermediary role. Interestingly, 9.71% have a betweenness centrality of zero, indicating that they are peripheral districts.

Closeness centrality reflects the reachability of a district to all others in the network. All districts in the network studied have a very low closeness centrality (close to zero), signifying that a district cannot connect to all others in the network. This is because of the location limitation of the network making all districts unable to connect to all others. This makes the network possessing low connection efficiency. Having a very low closeness centrality of all districts also reflects that transportation between almost all pairs of districts cannot be achieved directly but depends on one other intermediate district. However, the top ten districts with the largest are Na Khu, Khao Wong, Dong Luang, Kuchinarai, Mueang Mukdahan, Waeng Yai, Na Wa, Si Bun Rueang, Khamcha-I and Kaeng Khro. Thus, they have high reachability to others in the network.

Table 3
Top 15 districts with the highest values of betweenness centrality

Rank	District	Province	Betweenness Centrality
1	Na Khu	Kalasin	9644.41
2	Khao Wong	Kalasin	9341.8
3	Ban Khwao	Chaiyaphum	5895.53
4	Mueang Chaiyaphum	Chaiyaphum	5662.00
5	Pha Khao	Loei	5417.35
6	Waeng Yai	Khon Kaen	5281.99
7	Kuchinarai	Kalasin	4973.98
8	Khuang Nai	Ubon Ratchathani	4577.48
9	Nam Phong	Khon Kaen	4335.48
10	Prasat	Surin	4323.62
11	Na Wa	Nakhon Phanom	4186.75
12	Nong Bua Daeng	Chaiyaphum	4149.49
13	Rasi Salai	Si Sa Ket	4085.58
14	Mueang Mukdahan	Mukdahan	4068.87
15	Khon San	Chaiyaphum	3340.95

4.3 Export hubs of the region

Districts with a high degree and betweenness centrality are defined as hubs of the network since they have high connectivity and accessibility. Hubs act as a central point for consolidating agricultural products to export to China through the China–Laos railway. In Figure 2, eight districts in seven provinces are hubs of the network playing as a center consolidating agricultural products in the Northeast of Thailand, including Na Khu, Kuchinaria, Mueng Chiyaphum, Nam Phong, Na Wa, Mueang Mukdahan, Prasat and Rasi Salai. This is in line with the government's policy to set up some provinces as transportation hubs in this region. Nam Pong is one of Khon Kaen's districts, which the Thai government set as a transportation hub in the Northeast of Thailand. This is because it is in an economic corridor connecting industries and agricultural products. This upgrades the Thai logistics system to become a hub of trade, services and investment in Southeast Asia. The distance from Nam Phong to the China-Laos railway station in Vientiane, Laos is 170 kilometers.

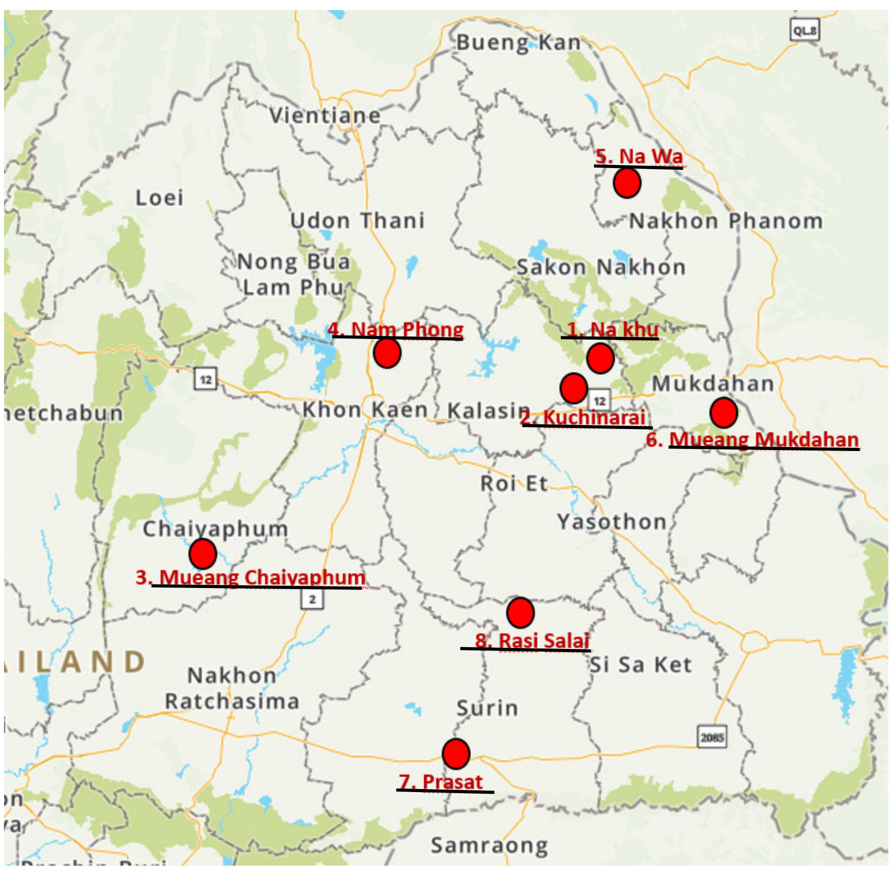

Fig. 2. Hubs of the road transport network in the Northeast of Thailand
Source: Author

Due to different provinces, different agricultural products or hubs mentioned above are very far away from some provinces, for instance, Loie, Nong Khai and Nong Bua Lam Phu. This causes a high transportation cost. Therefore, it is necessary to have a hub in every province to reduce the cost and respond to the transportation demand for the products. Table 4 shows the 20 districts are hubs of 20 provinces in the Northeast of Thailand, including Na Khu (Kalasin), Selaphum (Roi Et), Mueang Maha Sarakham (Maha Sarakham), Prathai (Nakhon Ratchasima), Mueang Buri Ram (Buri Ram), Rasi Salai (Si Sa Ket), Nam Phong (Khon Kaen), Prasat (Surin), Mueang Chaiyaphum (Chaiyaphum), Na Wa (Nakhon Phanom), Seka (Bueng Kan), Mueang Mukdahan (Mukdahan), Mueang Yasothon (Yasothon), Phu Kradueng (Loei), Phon Phisai (Nong Khai), Si Bun Rueang (Nong Bua Lam Phu), Pathum Ratchawongsa (Amnat Charoen), Ban Phue (Udon Thani), Det Udom (Ubon Ratchathani) and Sawang Daen Din (Sakon Nakhon).

Table 4
Hubs for consolidating agricultural products of provinces in the Northeast of Thailand

Province	Hub	Province	Hub
Kalasin	Na Khu	Bueng Kan	Seka
Roi Et	Selaphum	Mukdahan	Mueang Mukdahan
Maha Sarakham	Mueang Maha Sarakham	Yasothon	Mueang Yasothon
Nakhon Ratchasima	Prathai	Loei	Phu Kradueng
Buri Ram	Mueang Buri Ram	Nong Khai	Phon Phisai
Si Sa Ket	Rasi Salai	Nong Bua Lam Phu	Si Bun Rueang
Khon Kaen	Nam Phong	Amnat Charoen	Pathum Ratchawongsa
Surin	Prasat	Udon Thani	Ban Phue
Chaiyaphum	Mueang Chaiyaphum	Ubon Ratchathani	Det Udom
Nakhon Phanom	Na Wa	Sakon Nakhon	Sawang Daen Din

Source: Author

5. Conclusion

This study analyzes the road transport system (network) in the Northeast of Thailand to reflect its structural properties and find hubs for consolidating agricultural products to export to China through the China–Laos railway. An analysis is conducted using social network analysis. It has been found that the network consists of 340 districts connected by 1,015 transport routes. The network is a sparse network with a low density and a low connectivity efficiency with a larger average path length and diameter. The network districts in the same group (province) tend to connect to each other and rarely connect to others in different groups, reflected by a high clustering coefficient. In addition, the network has a high modularity structure having the ability to develop communities.

The network has a scale-free property with a small number of districts having a high degree and a larger number of districts having a low degree. 27 districts are important and popular nodes with the highest degree values. 15 districts with the highest accessibility are Na Khu, Khao Wong, Ban Khwao, Mueang Chaiyaphum, Pha Khao, Waeng Yai, Kuchinarai, Khuang Nai, Nam Phong, Prasat, Na Wa, Nong Bua Daeng, Rasi Salai, Mueang Mukdahan and Khon San. Therefore, these districts are intermediates of the network. There are no districts that have high reachability to all others due to the geographical constraint of the network.

Hubs of the network that consolidates agricultural products are Na Khu, Kuchinarai, Mueang Chaiyaphum, Nam Phong, Na Wa, Mueang Mukdhan, Prasat and Rasi Salai. Due to each province having different agricultural products, it is necessary to identify the hub of each province. Hubs of 20 provinces are Na Khu (Kalasin), Selaphum (Roi Et), Mueang Maha Sarakham (Maha Sarakham), Prathai (Nakhon Ratchasima), Mueang Buri Ram (Buri Ram), Rasi Salai (Si Sa Ket), Nam Phong (Khon Kaen), Prasat (Surin), Mueang Chaiyaphum (Chaiyaphum), Na Wa (Nakhon Phanom), Seka (Bueng Kan), Mueang Mukdahan (Mukdahan), Mueang Yasothon (Yasothon), Phu Kradueng (Loei), Phon Phisai (Nong Khai), Si Bun Rueang (Nong Bua Lam Phu), Pathum Ratchawongsa (Amnat Charoen), Ban Phue (Udon Thani), Det Udom (Ubon Ratchathani) and Sawang Daen Din (Sakon Nakhon).

The study's findings draw implications for the sector and policymakers. Policymakers can set the districts with high connectivity as hubs for consolidating agricultural products for export to China. However, they have to consider the types of agricultural products as different locations produce different products. Thus, policymakers should set hubs for each product type. Districts with low connectivity can promote themselves as hubs by having more connections, which can be done by creating new roads to other districts that have not been yet in the current network. This also helps to increase the efficiency of the districts and network. Policymakers can design a new road comprising hub districts to increase network connectivity and attract more visitors.

This study is subjected to some limitations. First, the present study only considered a binary network in which the weighted (distance) of a link was not taken into account. Future research should consider the distance of a road (link) that might affect the connectivity of the network and districts. Second, this study only analyzed the network based on a network perspective. To get insight into an analysis, future research should consider relevant policies that affect the transport system. Third, future research should consider other factors that might affect the network's structure.

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