Eduvest - Journal of Universal Studies
Volume 4 Number 09, September, 2024
p- ISSN 2775-3735- e-ISSN 2775-3727

CONNECTIVITY ANALYSIS OF NON-CONTAINER PORTS AT PT PELINDO MULTI TERMINAL USING SNA AND GIS

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ABSTRACT

This study aims to analyze the connectivity of non-containerized ports, particularly in the sub-commodity of vegetable/animal oils and fats, within the operational area of PT Pelindo Multi Terminal. Using Social Network Analysis (SNA) and Geographic Information System (GIS) techniques, this study builds a network based on nodes (ports) and assesses inter-node connections with metrics such as degree centrality, betweenness centrality, and hub index. Gephi application was used for the calculation of network metrics, while QGIS visualized the shipping routes. The research revealed that high traffic ports such as Belawan, Dumai, and Tanjung Priok play a crucial role in the network. The findings support recommendations for infrastructure development and implementation of an integrated Terminal Operations System (TOS) to improve logistics efficiency.

KEYWORDS *Connectivity, Non Container Port, Social Network Analysis, Geographic Information System, Pelindo*

INTRODUCTION

Ports play an important role in the connectivity of sea transportation modes, which is a key instrument for trade and the competitiveness of a country's economy (Farrell et al., 2018). In 2023, Indonesia's logistics performance declined in the Logistics Performance Index (LPI) to rank 61 with a score of 3.00 (Hidayat et al., 2024). The 2023 Linear Shipping Connectivity Index (LSCI) also shows a decline to 50th place, far below other ASEAN countries such as Singapore and Malaysia. This indicates problems in the national logistics system, especially related to port connectivity, even though Indonesia has more than 2,420 ports/terminals (Sinha, 2022). The large difference in logistics costs between the western and eastern regions of Indonesia indicates inequality in infrastructure and low efficiency of the logistics network (Vural et al., 2019). Previous government programs, such as the

How to cite:	Nailul Abror Pohan, Ahmad Perwira Mulia Tarigan, Zaid Perdana Nasution. (2024). Connectivity Analysis of Non-Container Ports at PT Pelindo Multi Terminal Using SNA and GIS. *Journal Eduvest. 4*(9): 8103-8117
E-ISSN:	2775-3727
Published by:	https://greenpublisher.id/

Pendulum Nusantara maritime network model (2012) and Tol Laut (2015), have not adequately resolved this issue.

On October 1, 2021, the Indonesian government issued Regulation No. 101 of 2021 on the Merger of PT Pelabuhan Indonesia I, II, III, and IV into PT Pelindo. This merger is a strategic step to strengthen connectivity and the national logistics network. PT Pelindo Multi Terminal (PMT) as one of Pelindo's subholdings is responsible for managing non-containerized terminals (NPK), specifically liquid bulk, dry bulk, and general cargo. PMT has a subsidiary that also manages NPK terminal operations, namely PT Pelabuhan Tanjung Priok (PTP) (PTP Non-container, n.d.). PMT's operational area is shown in Figure 1.

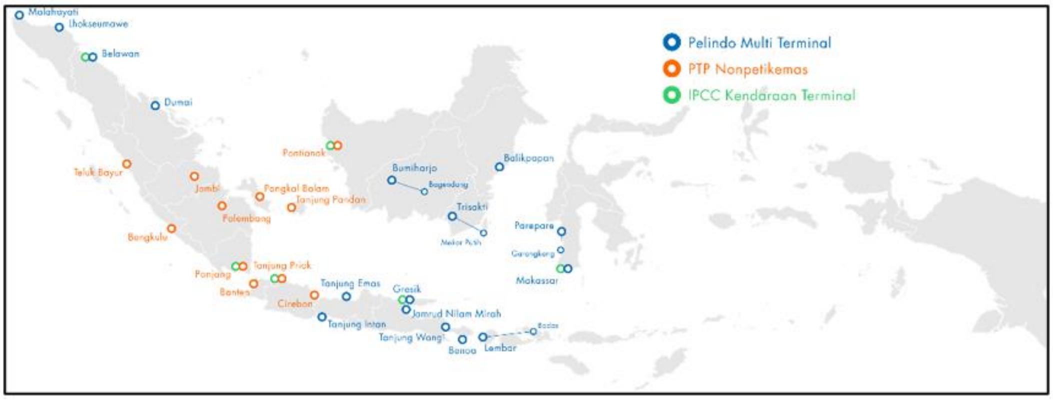


Figure 1. Subsidiary regions and terminals managed by PMT (PT Pelindo Multi Terminal, n.d.)

In the liquid bulk sector, the vegetable/animal oils and fats sub-commodity is a key commodity, with Indonesia being the world's largest palm oil producer. This makes the connectivity of these sub-commodities very important in supporting Indonesia's palm oil exports (Workman, 2023;(Tran et al., 2023)). However, Pelindo's market share in the NPK sector is still relatively low, only around 8% in 2019. In addition, many private ports compete in this sector. Therefore, it is important to understand the connectivity of liquid bulk ports in the NPK network. PMT, as the main manager of Pelindo's NPK terminal, has a great opportunity and challenge to strengthen the national logistics network. Liquid bulk was chosen because vegetable/animal oils and fats, especially palm oil, are leading export commodities that are very important to maintain and develop.

Marine transportation network research has used the Social Network Analysis (SNA) approach to quantitatively and graphically analyze port connectivity (Esteve-Pérez & del Río-González, 2022). In Indonesia, Moeis et al. (2022) applied it, while abroad, Park et al. (2017), Wanke et al. (2017), Mallick (2017), Lu, et al. (2018), Jeon, et al. (2019), Nguyen, et al. (2020), Lopez Rodriguez, et al. (2021), Nguyen and Woo (2021), Esteve-Pérez and del Río-González (2022) or Nguyen and Kim (2022) also conducted similar research. However, most of these studies focus on the port segment and container and cruise shipping.

This study focuses on analyzing the connectivity of non-container ports, specifically the sub-commodity of vegetable/animal oils and fats, using Social Network Analysis (SNA) and Geographic Information System (GIS). Previous port connectivity studies have predominantly focused on container and cruise ports, whereas this research not only introduces the SNA method but also incorporates GIS for a more comprehensive analysis. The novelty as well as the purpose of this research is to analyze the connectivity of non-container ports of vegetable/animal oil and fat sub-commodities in the operational area of PT Pelindo Multi Terminal based on historical port call data in the PMT operational area from January 1 to December 31, 2022. The data contains the name of the ship carrying out loading and unloading activities, origin and destination ports, commodities and the amount of loading and unloading cargo. Social Network Analysis (SNA) approach was used to determine the network properties (nodes, edges, and network density) and centrality (degree centrality, betweenness centrality, and hub and authority centrality (hub index), ports with high centrality values play an important role in the distribution of this sub-commodity. Geographic Information System (GIS) visualizes the pattern of shipping routes. This research provides a complete picture of the non-containerized port network by analyzing not only vessel traffic but cargo volume to generate recommendations for strategic hub ports to improve network connectivity efficiency.

RESEARCH METHOD

This research uses Social Network Analysis (SNA) and Geographic Information System (GIS) approaches. The process for this research is shown in Figure 2.

Data Retrieval

There are two data used in this study, namely historical port call data from 22 ports in the PMT operational area from January 1 to December 31, 2022 and coordinate data for each port formed. Port (of) call according to the European Union MRV Regulation is a port where ships load or unload cargo, or board or discharge passengers. The data contains the name of the vessel carrying out loading and unloading activities, port of origin and destination, commodity and the amount of loading and unloading cargo.

Data Preprocessing

Data preprocessing or data preparation is a technique applied to the database to remove noise, missing values, errors, unimportant data and inconsistent data so as to produce quality and accurate data (Sarasevia, 2021).

Data preparation carried out in the research, namely data cleaning, integration, and transformation using Microsoft Excel software. In the data cleaning process, port names were uniformed and their geographical coordinates were identified using UNECE web and Google Maps, so that complete and relevant data were ready for further analysis using Gephi and QGIS applications.

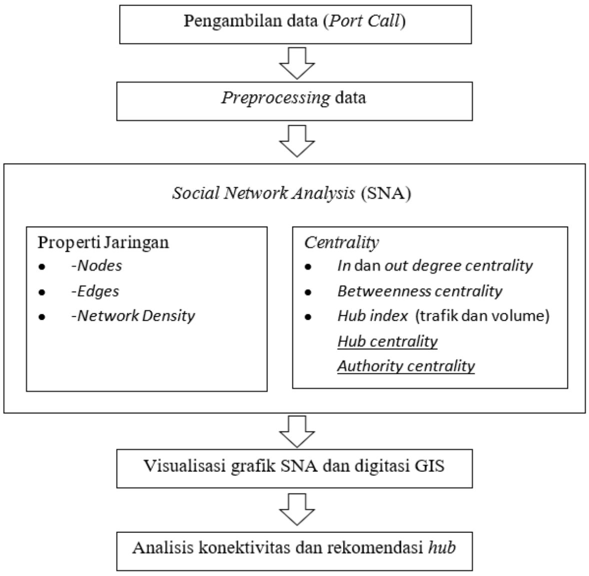


Figure 2: Research stages

Social Network Analysis (SNA)

SNA is a study of inter-actor relationships using graph theory, where ports are represented as nodes, and shipping routes as edges. The application of graph theory is considered capable of clearly depicting port connectivity (Esteve-Pérez & del Río-González, 2022). Maritime shipping networks are usually represented as directed graphs, where the direction of the edges indicates the port entry and exit routes (Nguyen & Woo, 2021).

Based on the level of analysis, SNA can be divided into two main groups, namely network properties and centrality (Bratawisnu and Alamsyah, 2019; Esteve-Pérez and del Río-González, 2022). Network properties are needed to understand a complex system, namely how the components in the system interact with each other (Bratawisnu & Alamsyah, 2019; Alamsyah & Ramadhani, 2020).

Some of the network properties used in this study are *nodes* representing ports in the network, *edges* representing shipping routes between ports, and *network density*. *Network density* is the ratio of the number of existing *edges* to the maximum number of possible *edges* in a network, indicating the maximum extent to which a particular type of cargo or product can be dispersed through different ports (Wanke and Falcão, 2017). *Network density* has a value that is between 0 and 1. The closer to 0, the looser the network (rarely connected) and vice versa, if it is close to 1 the network will be stronger and denser (many connected) (Alamsyah and Ramadhani, 2020). Mathematically, density (D) can be measured through equation (1) for directed graphs (Saylor Academy, 2021).

$$D = \frac{|E|}{|V|(|V|-1)} \tag{1}$$

where |*E*| denotes the number of *edges* (relationships between nodes) in the network and |*V*| = the number of *nodes* in the network (number of ports).

Centrality is a parameter that indicates the importance of individual nodes in the network, and is often used to determine actors in the network. Nodes with high centrality will be important in the network (Esteve-Pérez & del Río-González, 2022). Researchers usually use more than one type of centrality measurement in determining the main actors of a network.

This research uses the concepts of degree centrality, betweenness centrality, and hub and authority (hub index) to determine the connectivity analysis between ports in the PMT operational area.

Degree Centrality

It measures the number of direct connections a port has. *In-degree centrality* counts incoming routes to a port, while *out-degree centrality* counts outgoing routes (Freeman, 1978; Nguyen et al., 2020). *Degree* centrality $C_D(i)$ can be defined as follows.

$$C_{D-in}(i) = \sum_{j=1, j\neq i}^{n} X_{ji}\,;\ C_{D-out}(i) = \sum_{j=1, j\neq i}^{n} X_{ij} \quad (2)$$

where X_{ij} and X_{ji} equals 1 if *node* i and *node* j are connected, or 0 otherwise if ports i and j are not connected. Therefore, $C_D(i)$ is the number of ports connected to node i. $C_{D-in}(i)$ is *in-degree centrality, the* number of other ports that have direct shipping routes to *node* i, while $C_{D-out}(i)$ = *out degree centrality,* the number of other ports that can be reached by direct shipping routes from *node* i.

To obtain a normalized value, degree centrality is calculated using the formula (Nguyen and Woo, 2021).

$$I_i^{C_D} = \frac{C_D(i)}{n-1} \quad (3)$$

where $I_i^{C_D}$ is the normalized *degree centrality of node* I, $C_D(i)$ is the *degree centrality,* the number of ports connected to *node* I, and n is the number of *nodes* in the network

Betweenness Centrality

Measuring the role of a port as an intermediary in the shortest route between two other ports (Nguyen & Woo, 2021).

$$C_B(i) = \sum_{j<k}^{n} \frac{n_{jk}^{i}}{n_{jk}} \quad (4)$$

where$C_B(i)$ is *betweenness centrality*, n_{jk}^{i} is the number of *shortest paths* from port j to port k through port I, and n_{jk} is the number of *shortest paths* from port j to port k, and *n* is the number of *nodes* in the network.

To obtain the normalized value for a directed graph, the *betweenness* centrality is $C_B(i)$ is calculated with the formula (NetworkX, n.d.).

$$I_i^{C_B} = \frac{C_B(i)}{(n-1)(n-2)} \quad (5)$$

where $I_i^{C_B}$ normalized *betweenness centrality of node* i.

Hub and Authority Centrality

Hub and authority centrality is a concept that determines the *hub* and *authority* ports in the network. A port with a high *hub* value has many connections to an *authority* port. Conversely, ports with high *authority* values receive many connections from *hub* ports (Kleinberg, in Nguyen et al., 2020). The formula:

$$\sum_{p \epsilon S\sigma} (x^{(p)})^2 = 1 \quad (6)$$

$$\sum_{p \epsilon S\sigma} (y^{(p)})^2 = 1 \quad (7)$$

where $x^{<p>}$ is the *authority* weight for each *node* and $y^{<p>}$ is the *hub* weight for each *node*.

Although hub and authority centrality provides an overview of the importance of ports in the network, this index is less effective for determining the ideal hub port as it does not consider the port's traffic volume (Jeon et al., 2019). This index is more comprehensive than the other two as it assesses the concepts of centrality and accessibility, displaying the influence of ports as hub ports (Nguyen et al., 2020).

Previous research such as Jeon, et al. (2019), Nguyen, et al. (2020) and Esteve-Pérez and del Río-González (2022) used the number of shipping networks against hub and authority centrality. The criteria for a hub port is not only the number of vessel visits but also its ability to serve large volumes (Kavirathna et al., 2018). Therefore, the hub index was introduced to combine hub and authority centrality with port traffic or volume. Thus, the hub index provides a more accurate assessment of the hub port. The hub index is defined as follows (Nguyen, et al., 2020).

$$Hub\ index = \frac{\xi_p}{\xi_{max}} x \frac{(y_k + x_k)}{2} \quad (8)$$

where ξ_p is the vessel traffic/volume of a particular port, ξ_{max} is the sum of ship traffic/volume with the maximum number of ship traffic/volume, x_k is *authority centrality* and y_k as *hub centrality*.

Ports with above-average hub index values are considered important hubs. Jeon et al. (2019), Nguyen et al. (2020), and Esteve-Pérez & del Río-González (2022) have used this method to derive *hub* port recommendations.

In processing data and analyzing networks and visualizing networks, Gephi software or application is used. Gephi is a free and *open source* software or application used to process network analysis data (GEPHI, n.d.).

Geographic Information System (GIS)

GIS is a geographic data analysis tool that displays port locations as points, ship routes as lines, and port areas as polygons. The QGIS application is used in this study to digitize shipping routes and maps to obtain visualization of port geographic distribution patterns (Kurniawan & Setiaji, 2016; Budiyanto, 2016).

With the combination of SNA and GIS methods, this research is able to provide strategic recommendations for ideal *hub* ports based on their connectivity and volume in the marine transportation network.

RESULT AND DISCUSSION

The port call data obtained comes from the source of the front end application, which is an application used as a place for processing and managing and monitoring loading and unloading activities as well as stacking multipurpose goods and as a penning service activity for different businesses. The difference in front end applications causes the data obtained to have different data formats, such as port data with no destination.

In order to be modeled in Gephi, data must have two columns as data sources, namely data source (origin) and target (destination) as nodes. In the vegetable/animal oil and fat sub-commodity there are 8,338 data that will be analyzed further.

The results of the analysis show some information that can be used as recommendations for the development of marine transportation networks in Indonesia, especially in the PMT work area. Table 1 reveals that there are 282 nodes (ports) with 898 edges (shipping routes) and a network density of 0.011. The network is quite large and complex but has a low density indicating that although there are many ports, not all are directly connected to each other. This explains several things:

a. Bulk carriers often sail between raw material production sources and limited processing or distribution locations.
b. Bulk carriers are generally operated to transport one type of commodity in large quantities at a time, which may reduce route flexibility but increase efficiency for high-volume shipments. This could mean lower network density, but focusing on volume efficiency.
c. Bulk carriers focus on ports that specialize in certain bulk materials, which can be more geographically limited based on commodity production and consumption. This can result in a more focused and sometimes lower network density.

Table 1 Network properties

Nodes	282
Edges	898
Network Density	0,011

Tables 2 to 7 are the results of the calculation of the top 15 for SNA for in-out degree centrality, betweenness and hub and authority (hub index) which can then be used as a reference as a priority list for the development of transportation networks in this sub-commodity group.

Table 2 In-degree centrality of vegetable/animal oils and fats

Ranking	Port	*In-Degree*
1	Tanjung Priok	59
2	Long	54
3	Bayur Bay	50
4	Belawan	44
5	Pontianak	43
6	Tanjung Perak	42
7	Palembang	30
8	Dumai	25
9	Tanjung Wangi	25
10	Pangkal Balam	23
11	Kumai	21
12	Sampit	19
13	Jambi	16
14	Bengkulu	15
15	Cirebon	14

Table 3 Out-degree centrality of vegetable/animal oils and fats

Ranking	Port	*Out-Degree*
1	Belawan	103
2	Dumai	98
3	Tanjung Priok	69
4	Long	66
5	Pontianak	47
6	Bayur Bay	42
7	Palembang	21
8	Pangkal Balam	17
9	Jambi	16
10	Cirebon	15
11	Jakarta	12
12	Kumai	11
13	Marunda	11

Ranking	Port	*Out-Degree*
14	Gresik	11
15	Tanjung Perak	10

Table 4 Betweenness centrality of vegetable/animal oils and fats

Ranking	Port	BC
1	Belawan	0,143
2	Tanjung Priok	0,112
3	Long	0,102
4	Dumai	0,094
5	Bayur Bay	0,091
6	Pontianak	0,062
7	Tanjung perak	0,042
8	Palembang	0,028
9	Jambi	0,015
10	The base of the balam	0,012
11	Kumai	0,010
12	Sampit	0,007
13	Cirebon	0,007
14	Bengkulu	0,005
15	Kakinada	0,003

Table 5 Authority of vegetable/animal oils and fats

Ranking	Port	*Authority*
1	Tanjung Priok	0,290
2	Long	0,271
3	Bayur Bay	0,207
4	Belawan	0,201
5	Tanjung Perak	0,187
6	Tanjung Wangi	0,187
7	Pontianak	0,186
8	Dumai	0,181
9	Palembang	0,181
10	Pangkal Balam	0,163
11	Cirebon	0,163
12	Sampit	0,149
13	Jambi	0,138
14	Jakarta	0,133
15	Bengkulu	0,131

Table 6 Hub of vegetable/animal oils and fats

Ranking	Port	*Authority*
1	Dumai	0,440
2	Belawan	0,423
3	Long	0,303
4	Tanjung Priok	0,299
5	Pontianak	0,272
6	Bayur Bay	0,223
7	Palembang	0,152
8	Jambi	0,130
9	Kumai	0,125
10	Gresik	0,124
11	Marunda	0,122
12	Tanjung Perak	0,120
13	Jakarta	0,119
14	Pangkal Balam	0,116
15	Boom Baru/Palembang	0,109

Table 7 Hub index (traffic) of vegetable/animal oils and fats

Ranking	Port	ξ_p	ξ_{max}	x_k	y_k	*Hub Index*
1	Belawan	1.198	1.304	0,201	0,423	**0,287**
2	Dumai	1.150	1.304	0,181	0,440	**0,274**
3	Tanjung Priok	1.001	1.304	0,290	0,299	**0,226**
4	Long	759	1.304	0,271	0,303	**0,167**
5	Tanjung Perak	1.174	1.304	0,187	0,120	**0,138**
6	Bayur Bay	761	1.304	0,207	0,223	**0,125**
7	Sampit	1.304	1.304	0,149	0,101	**0,125**
8	Pontianak	560	1.304	0,186	0,272	0,098
9	Pangkal Balam	606	1.304	0,163	0,116	0,065
10	Palembang	436	1.304	0,181	0,152	0,056
11	Bengkulu	685	1.304	0,131	0,073	0,054
12	Jambi	492	1.304	0,138	0,130	0,051
13	Kumai	440	1.304	0,127	0,125	0,043
14	Jakarta	379	1.304	0,133	0,119	0,037
15	Marunda	395	1.304	0,120	0,122	0,037

Table 8 Hub index (volume) of vegetable/animal oils and fats

Ranking	Port	ξ_p	ξ_{max}	x_k	y_k	*Hub Index*
1	Belawan	3.508.597	3.508.597	0,201	0,423	**0,312**
2	Dumai	3.308.703	3.508.597	0,181	0,440	**0,293**

Ranking	Port	ξ_p	ξ_{max}	x_k	y_k	***Hub Index***
3	Bayur Bay	2.141.000	3.508.597	0,207	0,223	**0,131**
4	Tanjung Priok	1.484.549	3.508.597	0,290	0,299	**0,125**
5	Tanjung Perak	2.547.205	3.508.597	0,187	0,120	**0,112**
6	Long	1.267.577	3.508.597	0,271	0,303	**0,104**
7	Pontianak	932.845	3.508.597	0,186	0,272	0,061
8	Sampit	1.055.208	3.508.597	0,149	0,101	0,038
9	Jambi	968.344	3.508.597	0,138	0,130	0,037
10	Palembang	738.497	3.508.597	0,181	0,152	0,035
11	Kumai	742.213	3.508.597	0,127	0,125	0,027
12	Bengkulu	785.046	3.508.597	0,131	0,073	0,023
13	Pangkal Balam	571.176	3.508.597	0,163	0,116	0,023
14	Kabil	639.713	3.508.597	0,127	0,107	0,021
15	Jakarta	568.908	3.508.597	0,133	0,119	0,020

The Port of Tanjung Priok has the highest *in-degree* in receiving this sub-commodity and making it the main destination port, while the Ports of Belawan and Dumai have the highest *out-degree* respectively indicating its role as the main center of sub-commodity distribution. These two ports also have a relatively high *in-degree* indicating their receiving capacity as destinations is also significant.

Based on the *betweenness centrality* analysis, Belawan Port has the highest value which confirms its important role in the network as a *hub* and shows its strategic location and important role in connectivity.

Based on *authority*, Tanjung Priok Port has the highest value which confirms its position as the main destination port, while Dumai Port followed by Belawan has the highest hub which shows its position as the main distribution port and its effectiveness in sending cargo.

The average traffic *hub index* for the top 15 ports is 0.119. Ports with a *hub index* higher than the average are classified as *hub* ports. As a result, the *hub index of* Belawan Port (0.287) is the highest, followed by Dumai (0.274), Tanjung Priok (0.226), Panjang (0.167), Tanjung Perak (0.138), Teluk Bayur and Sampit (0.125).

The average *hub index* volume for the top 15 ports is 0.091. Ports with a *hub index* higher than the average are classified as *hub* ports. As a result, the *hub index of* Belawan Port (0.312) is the highest, followed by Dumai (0.293), Teluk Bayur (0.131), Tanjung Priok (0.125), Tanjung Perak (0.112), and Panjang (0.104). The ports of Belawan, Dumai, Tanjung Priok, Tanjung Perak, Teluk Bayur, and Panjang are consistently classified as hub ports in both traffic and volume.

Figures 3 and 4 show the visualization of the SNA formed, the thickness of the line indicates the intensity of traffic between ports both traffic density and cargo volume. The digitized map (Figure 5) is able to provide a geographical understanding of the position of the port and the connectivity formed between the *hub* and *spoke* ports.

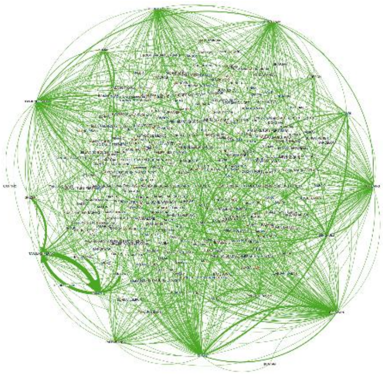
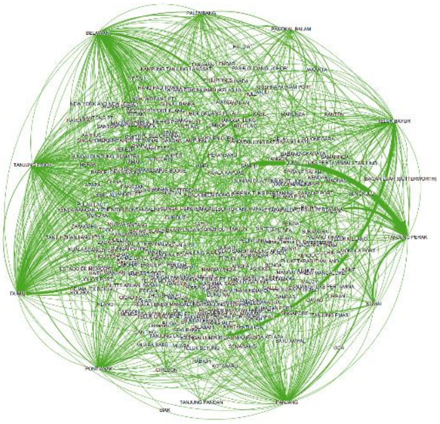


Figure 3. Network visualization (traffic) of vegetable/animal oils and fats



Network visualization (volume) of vegetable/animal oils and fats

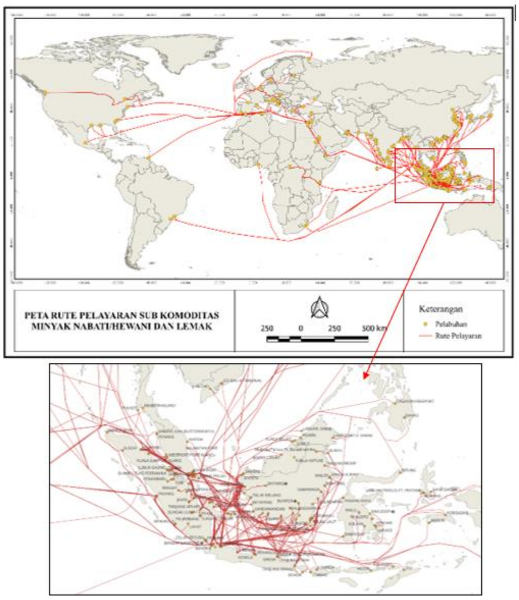


Figure 5. Sub-commodity shipping route map vegetable/animal oils and fats

CONCLUSION

The study confirms the important role of major ports such as Belawan, Dumai and Tanjung Priok in the distribution network of edible/animal oils and fats in Indonesia. These ports are also recommended alongside other ports, namely Tanjung Perak, Teluk Bayur and Panjang. While there are many ports, only a few have strong direct connections, which are vital in supporting national logistics efficiency and international trade. The low network density indicates limited direct connectivity, which implies a focus on the efficiency of high-volume shipments through strategic ports. Visualization through GIS reinforces this understanding by geographically displaying how these ports are connected and operate.

In an effort to improve port management and efficiency in Indonesia, it is recommended that PMT adopt a uniform Terminal Operations System (TOS). This system will enable integration and optimization of data management across ports, including synergies with the Ministry of Transportation's Inaportnet data. This will create a more holistic view and support strategic decision-making, as well as facilitate better coordination between private ports and Pelindo. In addition, infrastructure improvements at major ports are needed to increase capacity and operational efficiency.

However, previous research shows some limitations such as reliance on secondary data that may not accurately reflect current conditions and analysis that is limited to inter-port connections without considering internal operational aspects. To address this, it is recommended that future research use more extensive and up-to-date primary data with a longer time series. This will allow for a more in-depth analysis of port network trends and stability, providing new insights for the development of a more efficient marine transportation network in Indonesia. The integration of qualitative and quantitative methods in the research will also help in gaining a more comprehensive understanding of port operational dynamics.

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