Connectivity model of archipelagic areas: a case study of Kepulauan Riau

T Achmadi¹, H I Nur¹, F N Banjarnahor¹, S Kuik², E W Ardhi¹, C B S Permana¹ and M Riduwan¹

¹ Department of Marine Transportation Engineering, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
² Research and Development, Sembcorp Marine Ltd., Singapore

e-mail: hasaniqbal@seatrans.its.ac.id

Abstract. Marine transportation plays a vital role in the development of Kepulauan Riau as an archipelagic province. The GRDP 2017 of Kepulauan Riau shows that Batam city contributed the most to the figures, which amounted to 64%, followed by other cities outside Batam at 8.54%, and other districts are only under 10%. This condition might be caused by the lack of connectivity and network accessibility between those areas. The growth of passengers and general cargo in Kepulauan Riau was predicted to increase in the next few years, so there must be an improvement in marine services. This study aims to determine the conditions of connectivity for marine transportation in Kepulauan Riau using a degree connectivity matrix and a model for calculating the unit costs. The region with the highest passenger connectivity value is Tanjungpinang (0.83), while general cargo is Tanjungpinang and Batam (0.83). The effect of increasing connectivity to existing conditions and the results of an analysis of services between regions that have the smallest unit cost difference is Karimun-Bintan (IDR 6,881/ton or USD 0.48/ton), and the most significant difference is Natuna-Lingga (IDR 1,568,442/ton or USD 110.26). In terms of time, the slightest difference is Batam-Natuna (3 hours), and the most significant difference is Bintan-Lingga (1,001 hours).

1. Introduction
Several factors determine Indonesia's economic growth, and the most influencing factor is the connectivity between one area to another, connectivity is related to transportation services [1]. Kepulauan Riau is a province with the highest number of domestic and international ship calls in Indonesia. Based on data from the Indonesian Central Bureau of Statistics, it shows that the ports in Kepulauan Riau were visited by 138,349 ships for domestic shipping routes and 65,495 ships for international shipping routes. Marine transportation plays a vital role in the development of Kepulauan Riau as an archipelagic province, its geographical and demographic characteristics [2,3].

GDRP of Kepulauan Riau in 2017 shows that Batam city contributed the most, which amounted to 64%, followed by other cities outside Batam at 8.54%, and other districts are only under 10% [4]. In this case, there are possibilities that the difference is related to the level of connectivity and network accessibility. This condition might be caused by the lack of connectivity and network accessibility between those areas. The growth of passengers and general cargo in Kepulauan Riau was predicted to increase in the next few years, so there must be an improvement in marine services [5-7]. Passenger ships operating in the Riau Islands, in general, are High-Speed Ferry with 200-300 passengers, speedboats, and Pelni vessels. General Ship Cargo that operates in the Riau Islands is a ship that can
hold from 200 up to 2,000 tons. For sea transportation between the districts of Batam City from the islands such as Rear districts of Padang Padang and Bulang generally use small boat-sized vessels with a maximum of 16 passengers.

This study aims to determine port connectivity in the Kepulauan Riau region and accessibility between sub-districts in each city and district as well as strategy that can support increased connectivity between ports in the Kepulauan Riau region. The ports connectivity index calculation uses the degree connectivity method where the level of connectivity is determined by the number of routes or the number of districts or cities with the largest connected port [8-10].

2. Methodology

2.1 General Overview

In this study, the objectivity index calculation was carried out in two parts. Firstly, the port connectivity index calculation uses the degree connectivity method where the level of connectivity is determined by the number of routes or the number of n districts or cities with the largest connected port owned by the port j. Based on the transportation shipping network data, a connectivity matrix can be prepared, which is the initial iteration of the port and passenger port connectivity levels between regencies/cities in Kepulauan Riau Province. Figures 1 – 7 show the port locations in Kepulauan Riau Province.

Secondly, the analysis of the cost of marine transportation of passenger ships, high-speed ferries and general cargo ships, and each unit of cruise mileage (nm). From this calculation, it can be seen that if connectivity is added in the form of new routes that do not yet exist, what is the minimum cost per passenger required, and can compare the current rates with the results of the analysis.

Batam City has 15 ports consisting of 3 main ports, one collecting port, nine regional feeder ports, and two local ports. Tanjungpinang City has 28 ports consisting of 3 Collecting Ports, 5 Regional Feed Ports, and 7 Local Feed Ports. Tanjungpinang City does not have a leading port. Bintan Regency has 35 ports consisting of 5 Collecting Ports, 1 Regional Feeding Port, and 29 Local Feeding Ports.

Karimun Regency has 12 ports consisting of 1 Main Port, 4 Collecting Ports, 2 Regional Feeding Ports, and 5 Local Feeding Ports. Anambas Islands Regency has four ports consisting of 2 Collecting Ports and 2 Local Feeding Ports.

Lingga Regency has 19 Ports consisting of 12 Collecting Ports, 4 Regional Feeding Ports, and 3 Local Feeding Ports. Natuna Regency has 18 ports consisting of 11 Regional Feeding Ports and 7 Local Feeding Ports.
Figure 1. Port locations in Batam City

Figure 2. Port locations in Tanjungpinang City

Figure 3. Port locations in Bintan Regency

Figure 4. Port locations in Karimun Regency

Figure 5. Port locations in Kepulauan Anambas Regency

Figure 6. Port locations in Lingga Regency
2.2 Mathematical Models

Connectivity is the relationship between nodes or points connected by links or lines. Port is a form of node or point, and mode of transportation is a form of link or line [11,12]. The most basic method to measure the accessibility includes network connectivity, where a network is displayed as a connectivity matrix (C1), which shows the connectivity of each point or region with other points adjacent to it. The number of columns and rows in the matrix is the same as the number of points in the network and is one if there is a connection or connection between points and is 0 if no pair of points is connected.

\[
C1 = \sum_{j} C_{ij}
\]

(1)

\[
C_{ij} = \begin{cases} 
1, & \text{if } i - j = \text{connected} \\
0, & \text{if } i \neq j 
\end{cases}
\]

(2)

where:

- \(C1\) = Degree of a node
- \(C_{ij}\) = Connectivity between i and j (1 or 0)
- \(n\) = Node

The connectivity matrix does not consider all the possible indirect paths between nodes. In such circumstances, two nodes can have the same degree but may have different accessibility. The total accessibility matrix is used to calculate the total number of lines in the network, which includes both direct and indirect lines. The calculation is as follows:

\[
T = \sum_{k=1}^{D} C_k
\]

(3)

\[
C_k = \sum_{i} \sum_{j} C_{ij}^k \times C_{ji}^{k-1} (\forall k \neq 1)
\]

(4)

where:

- \(D\) = Network diameter
- \(T\) = Total accessibility

In general, shipping cost are capital costs, operational costs, voyage costs, and cargo handling costs [13,14]. These costs need to be classified and calculated to estimate the level of funding requirements for a specified period (economic life of the ship) [15,16]. So, the total cost can be formulated:

\[
UC = \frac{CC + OC + VC + CHC}{Demand}
\]

(5)

\[
OC = M + ST + MN + AD
\]

(6)

\[
VC = FC + PC
\]

(7)

where:

- \(CC\) = Capital Cost
- \(M\) = Manning Cost
- \(OC\) = Operational Cost
- \(ST\) = Provision Cost
- \(VC\) = Voyage cost
- \(MN\) = Maintenance Cost
- \(CHC\) = Cargo Handling Cost
- \(AD\) = Administration Cost
- \(Demand\) = General Cargo (ton) or Passenger (pax)

3. Results and Discussions

Passenger ships operating in the Riau Islands, in general, are High-Speed Ferry, speedboats with 200-300 passengers, and Pelni ships. General Cargo ships operating in the Riau Islands are vessels that can
hold from 200 to 2,000 tons. The various type of vessel and capacity uses for supporting the mobility of passengers in Kepulauan Riau shown in Table 1 below.

| Passenger Ship Routes       | Type of Vessel | Total (Ships) |
|-----------------------------|----------------|---------------|
| Batam - Tanjungpinang       | High-Speed Ferry 200 pax | 23            |
| Batam - Karimun             | High-Speed Ferry 200 pax | 21            |
| Batam - Lingga              | High-Speed Ferry 200 pax | 6             |
| Batam - Bintan              | Speed Boat      | 22            |
| Batam - Anambas             | High-Speed Ferry 300 pax | 2             |
| Batam - Natuna              | No Service      | -             |
| Tanjungpinang - Karimun     | High-Speed Ferry 200 pax | 10            |
| Tanjungpinang - Lingga      | High-Speed Ferry 200 pax | 10            |
| Tanjungpinang - Anambas     | High-Speed Ferry 300 pax | 2             |
| Tanjungpinang - Natuna      | No Service      | -             |
| Karimun - Lingga            | High-Speed Ferry 200 pax | 4             |
| Karimun - Bintan            | No Service      | -             |
| Karimun - Anambas           | No Service      | -             |
| Karimun - Natuna            | No Service      | -             |
| Lingga - Bintan             | No Service      | -             |
| Lingga - Anambas            | No Service      | -             |
| Lingga - Natuna             | No Service      | -             |
| Bintan - Anambas            | PELNI           | 1             |
| Bintan - Natuna             | PELNI           | 1             |
| Anambas - Natuna            | PELNI           | 1             |

Marine transport between district to Batam from sub islands such as Belakang Padang subdistrict and Bulang generally use small-sized vessels with passenger boats up to 16 people. Access from the Sekupang sub-district to Belakang Padang sub-district uses small-sized boats or commonly called “pompon,” which can accommodate 16 people.

For marine transportation access between islands such as Moro sub-district, they use a speed boat with a capacity of 60-80 passengers. Same with Moro sub-district, passenger and goods access from Durai sub-district use speed boat. With the location of the sub-district in the southern part of the Karimun district and bordering Jambi making ship services from Durai also go to the port in Jambi Province.

For marine transportation between the districts of Bintan Regency, access between the islands of the islands, such as the Bintan Pesisir sub-district, uses boats with a capacity of 15 passengers. In addition, there are inter-island boat services from the Bintan Regency government, KM Bahtera Numbing, and KM Mapur Indah. Then access from island districts such as Tambelan district, using the high-speed ferry "MV VOC Batavia“ from East Bintan district with a capacity of 150 passengers. The trip time from the subdistrict of East Bintan to Tambelan is 9 hours. Kapal Sabuk Nusantara 83 Also serves cargo to the Tambelan sub-district from Bintan Pesisir. Sanus 83 is a ship that carries passengers and goods. Besides, there are inter-island boat services from the Ministry of Transportation to the Bintan Regency government, the KM Banawa Nusantara 4 ship.

For marine transportation between the districts of Anambas Islands Regency, where the distance from Jemaja Island which consists of 2 districts to Siantan Island which consists of 5 districts is 37 nm so that marine transportation is needed for both islands. From the area accessibility data, it is known that ships serving the Jemaja and Siantan districts are high-speed ferries with a capacity of 250 passengers. One of the ships is MV Blue Sea Jet 01. The ship has the route Telaga Punggur - Letung (Jemaja district) - Tarempa (Siantan district). In addition, there is a speed boat service, SB Tobindo Express, which can carry 80 passengers with a 55-minute long journey at a cost of 150 thousand per passenger. Both ships
sail three times a week. For transportation, Central Siantan District with Pulmatak can be by land and sea. For Air Asuk village, whose territory is an island separated from the Pulmatak sub-district, it is connected by a ro-ro boat belonging to the Anambas district government.

For marine transportation between Lingga Regency sub-districts, access from archipelagic districts such as Senayang sub-district uses the high-speed ferry "MV Lintas Kepri" managed by BUMD Kepri to Lingga sub-district and with a capacity of 158 passengers. This ship has a route from Tanjungpinang - Pulau Benan - Rejai - Tanjung Kelit - Sungai Tenam - Jagoh - and Tanjung Buton. For the Posek islands sub-district, inter-sub-district transportation uses motorboats and speed boats.

For marine transportation between Natuna Regency sub-districts, access from the islands of the archipelago uses the General Cargo Ship, which used to transport passengers, "KM Terigas". General cargo is loaded into the cargo hold of the ship using unloading labor (TBM) and for passenger’s onboard cargo hold or main deck. This ship has a route in the Natuna region from Midai - Strait of Lampa (Pulau Tiga) - Sedanau (Bunguran Barat) - Pulau Laut - Penagi - Subi - Serasan. For Bunguran Utara sub-district, there are ships serving inter-island within the sub-district, the Banawa Nusantara 5 ship from the Ministry of Transportation to Natuna Regency. The ship operates from Seluan Island to Bunguran Utara.

Table 2. Comparison of passenger ship rates for Kepulauan Riau region routes

| Passenger Ship Routes         | Calculation (IDR/Pax) | Current Rates (IDR/Pax) | Existing | Deviation (IDR) |
|-------------------------------|-----------------------|--------------------------|----------|-----------------|
| Batam - Tanjungpinang         | 39,107                | 57,500                   | Ferry 200 Pax | 18,393          |
| Batam - Karimun              | 40,983                | 85,000                   | Ferry 200 Pax | 44,017          |
| Batam - Lingga                | 136,009               | 190,000                  | Ferry 200 Pax | 53,991          |
| Batam - Bintan               | 29,956                | 50,000                   | Speed Boat  | 20,044          |
| Batam - Anambas              | 199,085               | 450,000                  | Ferry 300 Pax | 250,915        |
| Batam - Natuna               | 285,250               | No Service               | -        | -               |
| Tanjungpinang - Karimun      | 75,785                | 180,000                  | Ferry 200 Pax | 104,215        |
| Tanjungpinang - Lingga       | 103,333               | 130,000                  | Ferry 200 Pax | 26,667         |
| Tanjungpinang - Anambas      | 204,949               | 490,000                  | Ferry 300 Pax | 285,051        |
| Tanjungpinang - Natuna       | 296,445               | No Service               | -        | -               |
| Karimun - Lingga             | 114,310               | 139,000                  | Ferry 200 Pax | 24,690         |
| Karimun - Bintan             | 89,556                | No Service               | -        | -               |
| Karimun - Anambas            | 219,756               | No Service               | -        | -               |
| Karimun - Natuna             | 314,751               | No Service               | -        | -               |
| Lingga - Bintan              | 131,208               | No Service               | -        | -               |
| Lingga - Anambas             | 277,266               | No Service               | -        | -               |
| Lingga - Natuna              | 365,837               | No Service               | -        | -               |
| Bintan - Anambas             | 188,756               | 198,000                  | PELNI    | 9,244           |
| Bintan - Natuna              | 277,326               | 248,000                  | PELNI    | 29,326          |
| Anambas - Natuna             | 170,097               | 138,000                  | PELNI    | 32,097          |

Notes: exchange rate is USD 1.0 = IDR 14,225

Table 2 above shows the cost per passenger on each possible route within the Kepulauan Riau Province. The unit cost analysis results obtained from the calculation of capital costs, voyage cost, which is the cost of ship fuel and clean water during the trip, and operational costs, is the cost of ship lubricants, salary, and crew insurance and administration. In general, the size of passenger ships operating in the Kepulauan Riau region can accommodate passengers around 200 - 300 people, so the size of the ship is used in capital costs. The index of port connectivity for each city/district in Kepulauan Riau with the degree of connectivity show in Table 3.
Table 3. Index of port and passenger port connectivity in regencies and cities

| Cities /Districts | General Cargo | Connect. Level | Not Directly Connected | Passenger | Connect. Level | Not Directly Connected |
|-------------------|---------------|----------------|------------------------|-----------|----------------|------------------------|
| Batam             | 0.83          | High           | Natuna                 | 0.67      | High           | Anambas, Natuna        |
| Tanjung Pinang    | 0.83          | High           | Natuna                 | 0.83      | High           | Natuna                 |
| Karimun           | 0.50          | High           | Bintan, Anambas, Natuna| 0.50      | High           | Bintan, Anambas, Natuna|
| Bintan            | 0.33          | Low            | Karimun, Lingga, Anambas, Natuna| 0.33 | Low | Karimun, Lingga, Anambas, Natuna |
| Kepulauan Anambas | 0.50          | High           | Karimun, Lingga, Bintan | 0.33      | High           | Karimun, Lingga, Bintan, Natuna |
| Lingga            | 0.50          | High           | Bintan, Anambas, Natuna| 0.50      | High           | Bintan, Anambas, Natuna |
| Natuna            | 0.17          | Low            | Batam, Tanjung, Pinang, Karimun, Bintan, Lingga| 0.17 | Low | Batam, Tanjung Pinang, Karimun, Bintan, Lingga |

Unit cost analysis results obtained from the calculation of marine transportation costs are the current capital cost of general cargo vessels, voyage costs from ship fuel costs, supplies, and clean water during the trip, and operational costs from ship lubricant costs, salary and crew insurance, and administration. In general, the size of cargo ships operating in the Riau Islands region has a DWT of around 300 to 2,000 tons, and the size of the ship used in the calculation is the ship with a payload of 450 tons so that the size of the ship is used in capital costs. The results of the calculation of increased connectivity to costs and time are in Table 4.

Table 4. Increased port connectivity of general cargo to unit costs

| Origin          | Destination | Total Transit | Existing Unit Cost (IDR/Ton) | If Directly Connected Unit Cost (IDR/Ton) | Difference (IDR/Ton) |
|-----------------|-------------|--------------|------------------------------|------------------------------------------|----------------------|
| Batam           | Natuna      | 1            | 227,473                      | 240,747                                  | 13,274               |
| Tanjung Pinang  | Natuna      | 1            | 174,735                      | 188,440                                  | 13,705               |
| Karimun         | Bintan      | 1            | 59,661                       | 66,542                                   | 6,881                |
| Karimun         | Anambas     | 1            | 27,448                       | 1,023,711                                | 996,263              |
| Karimun         | Natuna      | 2            | 39,387                       | 730,338                                  | 690,951              |
| Bintan          | Karimun     | 1            | 18,602                       | 66,577                                   | 47,975               |
| Bintan          | Anambas     | 1            | 27,009                       | 987,963                                  | 960,954              |
| Bintan          | Lingga      | 1            | 21,942                       | 233,761                                  | 211,820              |
| Bintan          | Natuna      | 2            | 38,483                       | 710,998                                  | 672,516              |
| Anambas         | Karimun     | 1            | 326,912                      | 1,017,605                                | 690,693              |
| Anambas         | Bintan      | 1            | 704,499                      | 987,963                                  | 283,464              |
| Anambas         | Lingga      | 1            | 1,035,325                    | 2,966,511                                | 1,931,185            |
| Lingga          | Bintan      | 1            | 194,334                      | 256,902                                  | 62,568               |
| Lingga          | Anambas     | 1            | 401,775                      | 1,617,379                                | 1,215,604            |
| Lingga          | Natuna      | 2            | 275,147                      | 1,094,061                                | 818,913              |
| Natuna          | Batam       | 1            | 214,288                      | 180,721                                  | 33,567               |
### Table 5. Increased port connectivity of general cargo to shipping time

| Origin   | Destination | Total Transit | Existing (Hour) | If Directly Connected (Hour) | Difference (Hour) |
|----------|-------------|---------------|-----------------|-----------------------------|-------------------|
| Batam    | Natuna      | 1             | 95              | 98                          | 3                 |
| Tanjung Pinang | Natuna  | 1             | 110             | 115                         | 5                 |
| Karimun  | Bintan      | 1             | 461             | 138                         | 323               |
| Karimun  | Anambas     | 1             | 374             | 36                          | 338               |
| Karimun  | Natuna      | 2             | 406             | 60                          | 346               |
| Bintan   | Karimun     | 1             | 1,139           | 138                         | 1,001             |
| Bintan   | Anambas     | 1             | 379             | 31                          | 348               |
| Bintan   | Lingga      | 1             | 363             | 70                          | 293               |
| Bintan   | Natuna      | 2             | 411             | 54                          | 357               |
| Anambas  | Karimun     | 1             | 380             | 36                          | 344               |
| Anambas  | Bintan      | 1             | 365             | 31                          | 334               |
| Anambas  | Lingga      | 1             | 46              | 25                          | 21                |
| Lingga   | Bintan      | 1             | 380             | 70                          | 310               |
| Lingga   | Anambas     | 1             | 79              | 29                          | 50                |
| Lingga   | Natuna      | 2             | 110             | 63                          | 47                |
| Natuna   | Batam       | 1             | 110             | 115                         | 5                 |
| Natuna   | Tanjung Pinang | 1         | 69              | 63                          | 6                 |
| Natuna   | Karimun     | 2             | 411             | 60                          | 351               |
| Natuna   | Bintan      | 2             | 396             | 54                          | 342               |
| Natuna   | Lingga      | 2             | 74              | 55                          | 19                |

The unit cost of cargo transportation services with general cargo between regencies/cities in Kepulauan Riau, which has the smallest difference, is Karimun-Bintan service, which is IDR 6,881/ton, and the most significant difference is Natuna-Lingga service which is IDR 1,568,442/ton. The results of the calculation of the increase in general cargo connectivity over time, as shown in Table 5 below.

### 4. Conclusions

A study on the connectivity model of archipelagic areas with the case study of Kepulauan Riau Province has been conducted, with conclusions:

- Marine transportation for passengers in Kepulauan Riau Province comprises, firstly, a speedboat for Batam-Bintan services. Secondly, a high-speed ferry with a capacity of 200 passengers for the services of Batam, Tanjungpinang, Karimun, Lingga, and with a capacity of 300 passengers for the services of Batam-Anambas, Tanjungpinang-Anambas. Thirdly, Pelni ships for the Anambas-Natuna route. For inter-sub-district marine transportation using wooden ships, boats, speedboats, and Pelni ships.
• The highest connectivity index for the port of cargo is Batam and Tanjungpinang, with a value of 0.83, and the lowest is Natuna with a value of 0.17. While the connectivity index for the passenger port is Tanjungpinang with a value of 0.83, and the lowest is Natuna with a value of 0.06. If the connectivity index is improved, the impact on existing conditions with the results of the analysis of services between districts/cities that have the lowest unit cost difference is the Karimun-Bintan service, which is IDR 6,881/ton (USD 0.48). The most significant difference is the Natuna-Lingga service, which is IDR 1,568,442/ton (USD 110.26). In terms of time, the service that has the smallest difference is service Batam - Natuna is 3 hours, and the most significant difference is the service Bintan - Linga in the order of 1,001 hours.

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