Navigation Channel Capacity Modeling: A Case Study for Balikpapan Bay

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Abstract. Vessel traffic flow in Balikpapan Bay will increase to follow the nation’s new capital city planning development in East Kalimantan affects the demand for development on a large scale from all around Indonesia to the new area in East Kalimantan. This final project aims to determine the maximum number of vessels passing a particular channel per unit time. The discrete simulation method will use Anylogic software to determine the channel capacity with the channel length, vessel safety distance, and vessel velocity. The number of vessel arrival to Balikpapan Bay is estimated using the Forecasting Method and Moving Average Method. The results showed that the recommended channel capacity is 74 units/day or equal to 27,010 units/year with a utility rate of 80%. That maximum number of vessels entering the channel can guarantee the safety level of shipping activities and reduce queues that cause congestion and costs arising from long waiting times for channel services and the stability of port workload. Based on these conditions, Balikpapan Bay could accommodate vessel arrival during materials and heavy-duty equipment for the nation’s new capital city planning development until 2032. The total number of vessel arrival is 24,282 units and a utility rate of 72%.

1. Introduction

Balikpapan Bay is a bay in Indonesia, near Borneo Island close to the city of Balikpapan, East Kalimantan, Indonesia. Several public ports and private ports were also located in this area. Vessel traffic flow in Balikpapan Bay will increase to follow the nation’s new capital city planning development in East Kalimantan that affect the demand for development on a large scale from all around Indonesia to the new area in East Kalimantan. This happens because materials and heavy-duty equipment in Kalimantan are not available, so this development needs to deliver all the material and heavy-duty equipment needed from all around Indonesia to Kalimantan via marine transport. This is important to determine the maximum number of vessels passing a particular channel per unit time that can guarantee the safety level of shipping activities and reduce queue that cause congestion and cost arising from long waiting times for channel services and stability of port workload.

Research about the channel capacity have been conducted by previous researcher. Fuji and Tanaka (1971) [3], Nie, Y., Liu, K., Xin, X. & Yu, Q., (2017) [6], conducted channel-through capacity with empirical and simulation approaches. This paper focused on the types of vessels, vessel safety distance, vessel velocity and velocity difference in different vessel which are all related to vessel traffic flow are concerned.
The research objective is to determine a method to calculate the maximum number of vessels passing the channel per unit time in two-ways route. This research was conducted Balikpapan Bay that represents the characteristics of navigation channel with several public ports and private ports along the channel. Balikpapan Bay has sufficient depth and width navigable by several types of vessels such as container vessel, bulk carrier, general cargo, landing craft tank, tug and barge, passenger ship, liquid bulk cargo, gas carrier and others.

2. Methodology

2.1. Vessel Traffic Flow

Vessel traffic flow has been defined as the overall dynamic characteristics of continuous vessel that navigate in the same direction along the channel. The main parameters of vessel traffic flow are vessel arrival rate, vessel velocity, and so forth.

Vessel arrival rate refers to the number of vessels arriving at entrance of the channel per unit time that closely related to the total number of passing vessels and the degree of congestion of the channel. Vessel velocity considers two issues of vessel traffic flow, the velocity distribution range, and average velocity. Some researchers have proved that typical parameters of vessel traffic flow obey certain distribution. Vessel arrival rate complies with Poisson distribution and vessel velocity obeys the Normal distribution.

Besides the above two indexes, minimum safety distance between two vessels is another important parameter related to vessel traffic flow. Vessel interval a sub-concept of ship domain that refers to area where the other vessels are avoided from entering for the reason of safety (Fuji & Tanaka, 1971). The size of ship domain is closely related to such aspect as traffic density, visibility, vessel velocity, vessel type etc. For instance, high seas usually take 2 miles as a standard reference for vessel collision avoidance.

There is theoretical calculating mechanism of channel-through capacity that discovered by Nie, Y., Liu, K., Xin, X. & Yu, Q., 2017 with several parameter such as channel length, vessel arrival rate and velocity difference in different vessel that used to validate the simulation result. The time interval between two vessels concluded as the following formula:

\[ T_{12} = \frac{d_0}{V} \]  

\( T_{12} \) : Time interval  
\( d_0 \) : minimum safe distance  
\( V \) : vessel velocity

In this formula, the vessel velocity is a constant number. The vessel enters the waterway at a certain time interval. The number of vessels entering the channel per hour is shown as follows:

\[ C = 3600 \times \frac{V}{d_0} \]  

\( C \) : capacity per hour

In formula, \( d_0 \) and \( V \) are expressed by meter and meter per second respectively. In consideration of the above two situations, for the first situation when the front vessel velocity is greater than that of the second one, the probability of this situation is \( P_1 \). In the second situation when the velocity of the first vessel is smaller than the second one, probability indicated as \( P_2 \). To find out the distribution rule of the initial distance, the concept of initial interval expectation is shown as follows:
\[ E(d) = P_1 \times d_0 + P_2 \times d_1 \]  

(3)

\[ E(d) \]: average initial distance  
\[ P_1 \] : probability condition 1  
\[ P_2 \] : probability condition 2  
\[ d_i \] : initial distance vessel

The average initial distance of successive vessel entering the channel is replaced as initial interval expectation \( E(d) \). The channel through capacity expressed as follows:

\[ C = 3600 \times \frac{\bar{v}}{E(d)} \]  

(4)

\[ \bar{v} \]: average vessel velocity

3. Overviews

To solve the problem, a case study of Balikpapan Bay is conducted in this paper to analyses characteristic of vessel traffic flow. As shown in Figure 1, Balikpapan Bay located in near Borneo Island close to the city of Balikpapan, is typical two-waves channel with high traffic density with overall length of 27.48 nm and width of 400 meter. The hydrological conditions of this channel are superior with enough water depth, clear navigation visibility, and small waves.
Table 1. Anchorage Area of Balikpapan Bay

| Location | Area [HA] | Depth [mLWS] | Capacity [Unit] |
|----------|-----------|--------------|-----------------|
| Zone A   | 812.9     | > 30         | 10              |
| Zone B   | 464.51    | 12 – 30      | 10              |
| Zone C   | 132.12    | 15 – 26      | 3               |
| Zone D1  | 246.85    | 7 – 13       | 9               |
| Zone D2  | 101.76    | 8 – 20       | 3               |
| Zone E   | 228.57    | 6 – 16       | 8               |
| Zone F   | 96.16     | 7 – 22       | 3               |
| Zone G   | 48.39     | 5 – 15       | 2               |
| Zone H   | 34.15     | 11 - 17      | 2               |

Figure 2 The number of vessel arrivals in 2019

In this study, there are more than 45 public port and private port along Balikpapan Bay. It was recorded in 2019 that the total movements of goods reached more than 6,029,482 tons/year and total passengers more than 602,562 passengers with the number of vessel arrival of 11,723 units.

Table 2. Research Ports

| Location                        | Type                                |
|---------------------------------|-------------------------------------|
| Port of Semayang                | Passenger, general cargo, container |
| Kariangau ferry crossing        | Passenger                           |
| Penajam ferry crossing          | Passenger                           |
| PT. Pertamina RU V              | Oil/chemical                        |
| PT. Kutai Refinary Unit         | Palm oil                            |
| PT. Penajam Banua Taka          | Oil/chemical                        |
| Balikpapan Coal Terminal        | Coal                                |
| PT. Katim Kariangau Terminal    | Container                           |

By using the Input Analyzer software, this case study analyses, fits, and test the arrivals and departures reports of vessel in 2019. According to the data statistics and distribution test, the vessel interarrival of the channel follows the Poisson distribution with an average of two vessel per hour and the vessel velocity follows the Normal distribution in which average velocity is 2.98 and the standard deviation is 0.885 as shown in Table 3.

Table 3. Parameters of the channel

| Typical parameter | Distribution types       | Express model       | Unit         |
|-------------------|--------------------------|---------------------|--------------|
| Vessels arrive rate| Poisson distribution     | Poisson(0.37)       | Ship/hour    |
| Vessel velocity   | Normal distribution      | Normal(2.95,0.885)  | knot         |
4. Simulation Experiment

4.1. Vessel Traffic Flow
The operation model of vessel traffic system in the channel mainly includes two parts: the channel environment model and vessel traffic flow model, working together to show a real environment of vessel traffic system. Channel environment includes many sub factors such as channel length, width, water depth, etc. This paper focuses on two ways channel as the main parameter. Channel length, width, water depth, etc. Channel length will not restricted vessel operation and there is no turn or intersection interference is chosen. Meanwhile, channel depth ensures the normal navigation for all vessels and the effect of tide is eliminated in this model. Lastly, vessel overtaking is forbidden in the channel.

During the simulation of the vessel navigating process, to set up the simulation scenario, the following parameters are concerned: channel length, vessel minimum safety distance, vessel velocity, and vessel arrival rate. Based on statistical analysis of the vessel traffic situation at Balikpapan Bay. It is assumed that the minimum safety distance is around 1.000 m, and the average velocity is following the Normal distribution with average of velocity is 2.98 and the standard deviation is 0.885 knot.

In this part, a simulation scene is firstly designed for determined the maximum capacity of the channel in a day compared with the mathematical calculation. The probability of vessel arrival is 0.033 of 70 meters, 0.297 of 100 meters, and 0.600 of 200 meters, and 0.089 of 235 meters. Consequently, of the model result:

| Result               | Simulation | $V_1 = V_2$ | $V_2 > V_1$ |
|----------------------|------------|--------------|-------------|
| Capacity             | 92 units/day| 120 unit/day | 96 units/day|
| Capacity/year        | 33.580 units| 43.800 units | 35.040 units|
| Velocity             | Normal(2.98,0.885) | 3 knot       | 2 and 3 knot|
| Deviation            | -          | 10.220 units | 1.460 units |

The relationship between velocity and density is the higher of vessel velocity, the greater minimum safe distance between vessels is needed, which make a smaller number of vessels per nautical mile. In addition, several critical points in the channel make the movement of vessels is limited.

4.2. Model Development
For the development of the model channel capacity, the number of vessel arrivals is added based on the results of the projected vessel arrivals at each port along Balikpapan Bay and vessel arrival during material dan heavy-duty equipment for the nation’s new capital city planning development in 2024 - 2032.

| Heavy-duty Type            | Quantity [Unit] | Material | Quantity [Ton] |
|----------------------------|-----------------|----------|---------------|
| Excavator                  | 294             | Cement   | 30,366,623    |
| Truck                      | 673             | Asphalts | 3,939,210     |
| Bulldozer                  | 127             | Steel    | 3,168,932     |
| Vibration Roller           | 390             | Concrete | 37,157,684    |
| Concrete Pump Truck        | 704             |          |               |
| Truck Mixer                | 714             |          |               |
| Foundation Equipment       | 2               |          |               |
| Total                      | 2,904           | Total    | 74,532,449    |
Table 6. The number of vessel arrivals during the nation’s new capital city development in 2024 - 2031

| Year | Material [Ton]   | Heavy-duty [Unit] | Ship call |
|------|-----------------|-------------------|-----------|
| 2024 | 5,962,595.92    | 581               | 2,445     |
| 2025 | 7,453,244.90    | 436               | 3,040     |
| 2026 | 8,943,893.88    | 436               | 3,462     |
| 2027 | 11,179,867.35   | 348               | 4,543     |
| 2028 | 14,906,489.80   | 290               | 6,039     |
| 2029 | 11,179,867.35   | 290               | 4,539     |
| 2030 | 7,453,244.90    | 232               | 3,032     |
| 2031 | 4,471,946.96    | 146               | 1,826     |
| 2032 | 2,981,297.96    | 145               | 1,222     |

Table 7. Total number of vessel arrivals at Balikpapan Bay in 2024 - 2032

| Year | Vessel Arrival | Vessel arrival during development | Total  |
|------|----------------|-----------------------------------|--------|
| 2024 | 13.401         | 2.445                             | 15.846 |
| 2025 | 14.332         | 3.040                             | 17.372 |
| 2026 | 15.331         | 3.462                             | 18.973 |
| 2027 | 16.402         | 4.543                             | 20.945 |
| 2028 | 17.550         | 6.039                             | 23.589 |
| 2029 | 18.784         | 4.539                             | 23.323 |
| 2030 | 20.111         | 3.032                             | 23.143 |
| 2031 | 21.253         | 1.826                             | 23.358 |
| 2032 | 23.060         | 1.222                             | 24.282 |

Figure 3 Simulation of vessel arrival in 2032
Based on model development result in 2032 with the total number of vessel arrivals of 24.282 units, which could be accommodated by Balikpapan Bay with average of vessel arrivals is 67 units/day. Then in 2038 with the total number of vessel arrivals of 34.607 units, there were 577 units that could not be accommodates by Balikpapan Bay with average number of queues of 4 units/day. Meanwhile, in 2042 with a total number of vessel arrivals of 45.363 units, there were 12.155 units that could not be accommodates by Balikpapan Bay with average queue of 34 units/day.
Based on projected vessel arrivals at each port along Balikpapan Bay and vessel arrival during material dan heavy-duty equipment for the nation’s new capital city planning development in 2024 – 2032:

1. The utility rate of the channel in 2028 with total number of vessel arrival of 23,589 units is 72%.
2. The utility rate of the channel in 2035 has reached more than 80% with average number of vessel arrival of 74 units/day.
3. The utility rate of the channel in 2038 has reached more than 100% and needs development.
4. The recommended channel capacity is 80% with average number of vessel arrivals 0f 74 units/day.
5. Simulation Experiment

1. The maximum population of vessel with channel length of 27.48 Nm and width of 400 meters is 50 ships and total ships with the anchorage area are 89 ships.
2. The maximum capacity of the channel based on the simulation result provided with vessel velocity follows Normal distribution with average of 2.98 and standard deviation of 0.885 is 92 units/day.
3. The maximum capacity of the channel based on the mathematical calculation result provided with vessel velocity is a constant number of 3 knot is 120 units/day.
4. The maximum capacity of the channel based on mathematical calculation result provided with vessel velocity range of 2 and 3 knot is 96 units/day.
5. The recommended channel capacity is 80% with an average arrival of 74 units/ that can guarantee the safety level of shipping activities and reduce queues that cause congestion and cost arising from long waiting times for channel service and stability of port workload.
6. Balikpapan bay could accommodate vessel arrival during material dan heavy-duty equipment for the nation’s new capital city planning development until 2032 with the total number of vessel arrival is 24.282 units and a utility rate of 72%.

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