Analysis of Ferry Fleet Operation Planning: A Case Study of Ujung - Kamal Ports

P. Wuryaningrum\textsuperscript{1}, A. Mustakim\textsuperscript{1}, A. M. Sodik\textsuperscript{2} and C. B. S. Permana\textsuperscript{1}

\textsuperscript{1} Department of Marine Transportation Engineering, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember, Surabaya
\textsuperscript{2} PT. PAL Indonesia, Surabaya

Abstract. Ujung - Kamal Ports is a ferry port that connects the island of East Java with Madura Island. These ports have a distance of about 2.5 nautical miles with shipping times of approximately 30-45 minutes. Since the operation of the Suramadu Bridge in 2009, the flow of passenger and vehicle visits at the Ujung-Kamal ports has decreased. This causes shipping operators for the Ujung-Kamal ferry port to reduce fleet size and operating time. Not only that, the number of fleets operated is uncertain, this has resulted in an inconsistent schedule for ship departures. Besides that, it also resulted in many passengers having to wait or be late with ship departures. This study aims to plan the optimal Ujung-Kamal ferry operation. The method used in this research is the optimization method with scheduling problem. After optimizing the number of operating vessels, 2 ships were selected. The vessels are KMP Jokotole and KMP Tongkol. The ship sailing schedule in one day is 10 and 8 trips. The minimum cost for KMP Jokotole is IDR 6,357,855 per day and for KMP Tongkol is IDR 5,615,357 per day and the total cost per day is IDR 11,973,213.

Key words: ferry fleet, optimization method, scheduling problem

1. Introduction
Before the Suramadu Bridge, Ujung - Kamal Port was one of the ferry ports that was visited by many passengers. The Ujung - Kamal ferry port is an inter-island ferry port that connects Madura Island with Java Island which crosses the Madura Strait. This port connects Madura Island, namely the Port of Kamal with Ujung Port, which is located in Surabaya City [1], with a distance of about 2.5 nautical miles and a shipping time of approximately 25-30 minutes. Kamal port has been the main gateway to the island of Madura since the Dutch era. Since that time, the Port of Kamal Madura has played a very important role in terms of transportation and also the economy[2]. Over time, from year to year there has been a very significant development in this Kamal Port. When a few years ago Kamal Port was very busy, the bustle at this port almost never rested, every day many people went back and forth to enter Kamal Port, this port has facilities, namely 3 docks, garbata and several ships. Several ships that have operated, namely KMP Jokotole, KMP Trunojoyo, KMP Potre Koneng and KMP Madura 1 and 2 straits.

Since the operation of the Suramadu Bridge, which is expected to grow the economy in Madura [3], users of this port have experienced a drastic decline (up to 40%) [4]. Due to the tendency of vehicles to pass through the Suramadu Bridge compared to the port of Kamal, then the shipping operator reduced its fleet from initially having 19 fleets with an operational time of 24 hours to 3 fleets in just 16 hours. Not only that, the number of fleets operated is uncertain, this has resulted in an inconsistent schedule for ship departures. Besides that, it also resulted in many passengers having to wait or be late with ship departures.
2. Literature Review

This chapter describes a literature review of methods for optimizing the ferry route system. Passenger ferries have a route system that has the same characteristics as other transit systems in terms of objectives and constrain.

Ding et al. developed a ferry operational simulation method using micro traffic simulation modeling. Modeling is carried out using the VISSIM program in 2D and 3D analysis[5]. Mankowska conducted detailed market studies to predict passenger traffic that will be used as the basis for ferry route optimization. They identified the passengers' motivations for using the ferry and factors that made them choose ferries over other transportation modes[6]. Maiorov et al. made a simulation of the route network and ferry traffic intensity based on discretization and circos plot intensity diagram. With this method, they can perform an analysis by considering the number of passengers, ferry terminals, and the number of ferry operators[7].

3. Problem definition

The problem that becomes the focus of the object of research in this paper is to determine the optimal ferry operation at the Ujung-Kamal ports. The distance between the port of Ujung and the port of Kamal is 3 nautical miles with the route as in the Figure 1.

![Figure 1. Ujung – Kamal Ferry Shipping Route.](image)

Figure 2 shows that Kamal Port has 3 piers which are of the Mobile Bridge type or commonly called MB pier, each MB pier has different facilities. The MB I pier is located at the westernmost point of the port. The facility at this pier is a passenger bridge access that commonly called Garbarata that makes it easy for passengers to get on the ship without having to be obstructed by vehicles.[8] The MB II pier is located in the middle between the MB I and MB III pier, this MB II pier does not have facilities like other piers. This pier only has a road that is given a building to check tickets and fences for passengers who do not use vehicles, so that passengers on foot are avoided from vehicles that will enter or exit the ship. The MB III pier is located east of the port where this pier does not have the same facilities as the MB I pier, Garbarata, but the MB III pier still has a special lane for passengers who want to get on or off the ship so that it does not disturb motorized vehicle users or vice versa. The special lane is given a protective fence so that passengers on foot are not hit by a motorized vehicle besides that the special lane has a canopy or roof so that passengers are not exposed to rain during the rainy season.
Figure 2. Port of Kamal, Madura.  

Figure 3. Port of Ujung, Surabaya.

Figure 4 shows Ujung Port has 3 Mobile Bridge Docks or commonly called MB Docks. Each pier at the end port has different facilities, the MB I Pier, which is located in the south of the port, has a jet bridge which makes it easier for passengers to walk. Similar to the MB I pier, the MB II pier, which is located in the middle between the MB I pier and the MB III jetty, has a jet bridge facility and the MB III jetty is not equipped with a jet bridge, so that passengers on foot mix with motorized vehicles. however, this MB III pier has not been in operation for a long time considering the small number of fleets so that only MB I pier and MB II pier are operated.

Furthermore, for passenger data, sample data is taken for passenger visits for one month. The data is obtained from shipping companies serving the Ujung-Kamal route. The data is taken from the number of passengers on the ships that serve the route, namely KMP Gajahmada, KMP Tongkol and KMP Jokotole. Specifications of each ship can be seen at table 1.

| No. | Ship Specifications | KMP. Gajah Mada | KMP. Tongkol | KMP. Jokotole |
|-----|---------------------|----------------|--------------|---------------|
| 1.  | Ship Type           | Ferry/Ro ro    | Ferry/Ro ro  | Ferry/Ro ro  |
| 2.  | LOA (meter)         | 37,50           | 36,74        | 31,50         |
| 3.  | B (meter)           | 13,20           | 8,90         | 9,00          |
| 4.  | T (meter)           | 3,65            | 2,90         | 1,30          |
| 5.  | H (meter)           | 4,20            | 3,00         | 2,40          |
| 6.  | Vs (knot)           | 13              | 5            | 8             |
| 7.  | DWT (ton)           | 155             | 110          | 150           |
| 8.  | GT                  | 512             | 259          | 192           |
| 9.  | Capacity            |                 |              |               |
|     | Passenger (pax)     | 290             | 134          | 220           |
|     | Vehicle (unit)      | 18              | 18           |               |
| 10. | Power (HP)          | 1100            | 600          | 870           |

The number of passenger traffic for KMP Gajah Mada for one month is 37,916 passengers, with an average per day of 1,223 passengers. where the largest number of traffic reached 2184 in one day. Meanwhile, for KMP. Tongkol the number of passengers traffic for one month is 27,474 passengers, with an average per day of 886 passengers. where the largest number of traffic reached 1296 in one day. then for KMP. Jokotole has 32,253 passenger traffic per month, with an average of 1,040 passengers.
per day and where the largest number of traffic reached 1558 in one day. For more details about the passenger traffic on these vessels, see figure 4, figure 5 and figure 6.

![KMP Gajah Mada](image)

**Figure 4.** Passenger Traffic KMP. Gajah Mada.

![KMP Tongkol](image)

**Figure 5.** Passenger Traffic KMP. Tongkol.

![KMP Jokotole](image)

**Figure 6.** Passenger Traffic KMP. Jokotole.

4. **Research Methodology**

4.1 **Stages of Study**

There are six stages needed to solve the problems in this study as follows:

- **Identify the main problem**
  The first step is to identify the main problems that occur in the crossing in Ujung - Kamal which is affected by the operation of the Suramadu Bridge. The flow of passenger and vehicle visits at the Ujung-Kamal port has decreased. this causes shipping operators to reduce fleet size and operating time. So that the number of operated fleets is uncertain and the ship's departure schedule is not appropriate.

- **Analyze the current situation**
  This stage is carried out to determine the existing conditions regarding ferry shipping in Ujung - Kamal. The methodology to determine existing conditions with primary and secondary surveys and questionnaires to ferry service users.

- **Analyze the Shipping Cost**
  In this stage, calculate the shipping cost of all alternative ships that can operate in Ujung – Kamal. components in shipping cost are capital cost, voyage cost, operating cost and cargo handling cost. However, in this study, because the types of cargo are vehicles and passengers, cargo handling costs can be ignored.
• Determine the optimum schedule
  This stage is carried out to find out which ship will be selected to serve Ujung - Kamal and how the schedule is. The optimal scheduling will be determined by minimizing the total shipping cost. In choosing a ship, it will consider passenger demand and the maximum ship capacity. For the optimization model can be seen in the sub-chapter 4.2.

• Provide conclusions and future research
  This conclusion will provide the optimal scheduling and selected vessels to serve Ujung - Kamal. And the shipping cost that must be borne. In addition, suggestions regarding further research will be added at this stage.

4.2 Mathematical Model
  This paper focuses to obtain optimum solution for ship scheduling for Ujung – Kamal Ferry Transportation. Mathematical model for the optimization process is as below:

Objective Function:

\[
\min Z = \sum_{t=1}^{T} \sum_{v=1}^{V} C_{tv} X_{tv}
\]

Subject to:

\[
\sum_{v=1}^{V} X_{tv} \cdot P_v \geq D_t \quad t = 1,2,3,4, \ldots T
\]

\[
X_{tv} = \begin{cases} 
1, & \text{Vessel } v \text{ at time } t \text{ is assigned} \\
0, & \text{Vessel } v \text{ at time } t \text{ is not assigned}
\end{cases}
\]

Where:

\(X_{tv}\) : Decision assigned for vessel \(v\) time \(t\) \((1 = \text{is assigned}, 0 = \text{is not assigned})\)

\(C_{tv}\) : Cost of assigned for vessel \(v\) time \(t\) (IDR)

\(P_v\) : Transport Capacity of vessel \(v\) (pax)

\(D_t\) : Demand at time \(t\) (pax)

\(t\) : time in scheduling

Equation 1 represents the objective function to minimize total shipping cost. Where in the shipping cost calculation the fix cost and variable cost are calculated. The fixed cost component is the capital cost and operating cost, then the variable cost component is the voyage cost[9]. Equation 2 represents the Constraint of this optimization model. Constraint of this model is the ship capacity must be greater than passenger demand at a certain time. Time is the time according to ship scheduling in one day. Equation 3 represents for decision assigned for vessel at each time. And for the optimization model, the decision variable is a binary form.

5. Results and discussion
  In the previous section, it was mentioned that one of the methods to determine the existing conditions of the Ujung-Kamal ferry shipping was done by using a questionnaire to passengers.

5.1 Ferry service conditions from the response of users
  Figure 8 shows that the majority of Ujung - Kamal ferry service users are motorbike users, which is 80% and the others are trucks and pedestrians. Then for the type of work, it is almost equal for students and workers, namely 41% and 54% as can be seen in Figure 9. the largest use of ferry service time is 2-3 times per week at 40%, then 22% for 1-2 times per month, after that 20% for 1-2 times per week and 18% for daily use.
Furthermore, for the biggest customer satisfaction stated quite satisfied, namely 45% and 37% satisfied. For the existence of the Ujung - Kamal ferry service, 50% is very important and 45% important.

One of the most important things is the expectations of service users for the Ujung - Kamal ferry service time. From the survey results, it was found that 88% expected there was a ship schedule 24 hours per day and the remaining 12% was 12 hours per day as can be seen in Figure 13.

5.2 Analysis of Shipping Cost
Shipping costs include fixed costs and variable costs. To get the value of fixed costs and variable costs, several assumptions such as data on shipping distances, specifications and variations of fleets, ship
procurement costs, fuel, and port costs are used as the basis for calculations in the optimization model.
the component of fixed cost is capital cost and Operational Cost, while the component of variable cost is Voyage Cost. With the number of shipcalls in one year. The following will explain the proportions of each cost component in Table 2.

### Table 2. Shipping Cost.

| Cost             | KMP Tongkol | KMP Gajahmada | KMP Jokotole |
|------------------|-------------|---------------|--------------|
| Capital Cost     | 2.581.674   | 5.812.592     | 2.790.682    |
|                  | 78.525.915  | 176.799.659   | 84.883.238   |
|                  | 942.310.981 | 2.121.595.911| 1.018.598.860|
| Operational Cost | 9.225.008   | 10.566.978     | 9.284.936    |
|                  | 224.354.000 | 262.052.250   | 226.176.800  |
|                  | 3.367.128.000 | 3.856.947.000 | 3.389.001.600 |
| Voyage Cost      | 19.957.932  | 22.488.797     | 22.174.389   |
|                  | 598.737.958 | 670.683.191   | 665.231.684  |
|                  | 7.184.855.499 | 8.048.198.287 | 7.982.780.205 |
|                  | 31.764.614  | 38.868.367     | 34.250.007   |
|                  | 901.617.873 | 1.109.535.100 | 976.291.722  |
|                  | 11.494.294.480 | 14.026.741.198 | 12.390.380.665 |
| Total Cost       | 31.764.614  | 38.868.367     | 34.250.007   |

5.3 Optimization of Scheduling

Regarding the operation of 2 ships and 3 ships in 19 hours on the schedule, not every trip gets a lot of passengers, resulting in a loss in the voyage cost of each ship. Therefore, in this section scheduling optimization is carried out, the constraint of the scheduling is the time where the time is divided into 3 parts, namely Morning between 05.30 AM - 08.00 AM, then Afternoon between 12.00 PM - 1:00 PM and Evening between 4:00 PM - 7:30 PM. Besides that, the constraint is the capacity of the ship, where this capacity will be compared with the number of passengers at the 3 times. If the number of passengers is more than the capacity of the ship, the schedule will be added at that time. Scheduling optimization aims to reduce voyage costs.

From the calculation and optimization results, it is obtained the optimal ship assignment schedule as shown in Table 3. From the table, the value 1 is if the ship is assigned, and the value 0 is if not assigned. For the total schedule in one day, KMP Jokotole is assigned to each schedule and for KMP Tongkol is scheduled for the whole day except for the day. Meanwhile, for optimal results, only two ships were assigned and KMP Gajah Mada was not assigned.

### Table 3. Scheduling Optimization Results.

| Name of Ship | Morning | Morning | Afternoon | Evening | Evening |
|--------------|---------|---------|-----------|---------|---------|
| KMP Jokotole | 1       | 1       | 1         | 1       | 1       |
| KMP Tongkol  | 1       | 1       | 0         | 1       | 1       |
| KMP Gajah Mada | 0     | 0       | 0         | 0       | 0       |

### Table 4. Ship Departure Schedule.

| Port   | Ship     | Morning | Morning | Afternoon | Evening | Evening |
|--------|----------|---------|---------|-----------|---------|---------|
| Kamal  | KMP Jokotole | 5:30 AM | 7:10 AM | 12:00 PM | 4:00 PM | 7:20 PM |
|        | KMP Tongkol | 6:20 AM | 8:00 AM | 5:00 PM  | 9:00 PM |
| Ujung  | KMP Tongkol | 5:30 AM | 7:10 AM | 4:00 PM  | 7:20 PM |
|        | KMP Jokotole | 6:20 AM | 8:00 AM | 1:00 PM  | 5:00 PM | 9:00 PM |


Table 5. Total Trip and Total Cost.

| Ship       | Total Trip/Day | Cost/Day (IDR) |
|------------|----------------|----------------|
| KMP Jokotole | 10             | 6,357,855      |
| KMP Tongkol  | 8              | 5,615,357      |
| **Total Cost/Day** |                | **11,973,213** |

Table 4 displays the schedule of ship departures. This schedule is less than the previous schedule. This is because the existing schedule and the number of passengers have decreased, resulting in higher costs while the load factor is getting smaller. From the analysis, it is found that the optimal number of operating vessels is 2, namely KMP Jokotole and KMP Tongkol, where the number of trips for each ship is 10 trips for KMP Jokotole and 8 trips for KMP Tongkol. The total cost per day is IDR 11,973,213.

6. Conclusion

In this study, primary and secondary surveys were carried out, primary surveys of users of ferry transportation services and analysis of sea transportation cost calculations and optimization for ship scheduling and assignment. From these results, the following conclusions were obtained:

- The interest of users of ferry transportation services at the port of Ujung - Kamal is still high. This is obtained from the results of a service user questionnaire, where 95% of users think this transportation is important and very important, besides the expectations of service users that transportation services in Ujung - Kamal can operate 24 hours per day.

- Optimization results for ferry fleet scheduler obtained 2 ships assigned, namely KMP Jokotole and KMP Tongkol. For KMP Jokotole it operates 10 trips per day, while for KMP Tongkol it operates 8 trips per day.

- Ship scheduling is carried out 5 times per day, 2 times for the morning, 1 time for the afternoon and 2 times for the evening, where the number of vessels in operation for the entire time is 2 ship, except on the afternoon only one ship that is KMP Jokotole.

- From the calculation of shipping cost, where cost is an objectivity function in the scheduling optimization model. The minimum cost for KMP Jokotole is IDR 6,357,855 per day and for KMP Tongkol is IDR 5,615,357 per day and the total cost per day is IDR 11,973,213.

For the future research is important to conduct the stochastic problem optimization because the schedule of the vessel shows the stochastic properties.

References

[1] E. Apriliani, D. Irhamah, and J. Statistika, “Peramalan Pengguna Kapal Ferry Ujung-Kamal dengan Metode Intervensi,” Dec. 2016. doi: 10.12962/j23373520.V5s1.17624.
[2] S. Hotijah and H. Cahyono, “Perkembangan Industri Dan Pendapatan Daerah Kabupaten Bangkalan Sebelum Dan Sesudah Pembangunan Jembatan Suramadu,” 2013.
[3] E. Akbarwati, E. Akbarwati, and P. G. Ariastita, “Revitalisasi Kawasan Pelabuhan Kamal Di Madura,” J. Tek. ITS, vol. 2, no. 2, pp. C104–C108, Sep. 2013, Accessed: Nov. 21, 2020. [Online]. Available: http://ejurnal.its.ac.id/index.php/teknik/article/view/4324.
[4] S. (Sri) Amiranti and K. E. (Katherine) Permanasari, “928X Print),” Sepuluh Nopember Institute of Technology, 2013. doi: 10.12962/j23373520.V212.3807.
[5] L. Ding and S. Venglar, “Analysis for the Port Ferry Operation and Control Alternatives by Using Traffic Micro Simulation Modeling,” Procedia - Soc. Behav. Sci., vol. 43, pp. 805–812, 2012, doi: 10.1016/j.sbspro.2012.04.155.
[6] M. Mańkowska, “The Concept Of Development Of Passenger Ferry Services In The Baltic Sea Region In Terms Of The Growing Interbranch Competition,” no. May 2015, pp. 285–298, 2016.
[7] N. Maiorov, V. Fetisov, S. Krile, and D. Miskovic, “Simulation of the route network and ferry traffic intensity based on the process of discretization and circos plot intensity diagram,” Transp. Probl., vol. 14, no. 4, pp. 23–30, 2019, doi: 10.20858/tp.2019.14.4.2.
[8] A. Mustakim and F. Hadi, “Innovated Conceptual Design of Loading Unloading Tool for
Livestock at the Port,” in *Journal of Physics: Conference Series*, Mar. 2018, vol. 979, no. 1, p. 12061, doi: 10.1088/1742-6596/979/1/012061.

[9] P. Wuryaningrum, T. Achmadi, A. Mustakim, H. I. Nur, S. D. Lazuardi, and M. Kusumadewi, “Optimization of Product Oil Shipment System for Archipelagic Region,” *Rekayasa*, vol. 12, no. 2, pp. 120–125, Oct. 2019, doi: 10.21107/rekayasa.v12i2.5929.

[10] M. Stopford, *Maritime Economics Second Edition*. 1997.