A simulation study of the fleet sizing problem in pilotage and tug services: Case study of Tanjung Perak port, Surabaya

F Hadi\textsuperscript{1}, H Supomo\textsuperscript{2} and T Achmadi\textsuperscript{1}

\textsuperscript{1} Department of Marine Transportation Engineering, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember, Surabaya
\textsuperscript{2} Department of Naval Architecture, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember, Surabaya

Abstract. Pilotage and tug services are one of the essential services in port operation especially for ports which have channel like Tanjung Perak. There are important interactions between decision on sizing tugboats and decision on utilizing that fleet. This paper combines simulation and assignment model for supporting strategic fleet sizing problem at ports where a Monte Carlo simulation is built to capture the behavior of the real system, whereas the assignment model is built to allocate tugboats near optimal. This approach is quite flexible in the sense that the simulation part can deal with the stochastic aspects with a quite precision and the assignment model can easily change the tugboats configurations. The performance of the model developed is evaluated by comparing the real data and the simulation results with high precision. The methodology developed in this paper provided valuable decision support on strategic fleet sizing problems in pilotage and tug services at the port.

Key words: fleet sizing problem, assignment problem, pilotage and tug services, port performance

1. Introduction
Pilotage and tug services are one of the essential services in port operation not only to assist ship in the berthing process, but also to escort ships passing through the channel (for ports with channel). Therefore, providing efficient pilotage and tug services will largely determine the overall port performance, especially for ports with heavy traffic. The provision of pilotage and tug services can be viewed from two perspectives, first as a special service for shipping operators and secondly as a public service because of the potential of accidents [1].

To provide an efficient pilotage and tug services, port authority or port operator requires sufficient tugboats not only in term of quantity, but also in term of power. If the number of tugboats is not enough, congestion will arise at the port which result in losses suffered by shipping operators and loss of potential revenue for the port. Conversely, if the number of tugboats is excessive, the utility of tugboat will be low which will result in higher cost due to high fixed costs of tugboats. In addition, when the number of tugboats is insufficient, the port authority or port operator can charter a tugboat from another party to make up for the shortage of tugboats. However, this will have an impact on high cost due to higher charter rate (especially in the short-term charter). Therefore, deciding on the number of tugboats that must be owned by port authority or port operator is an important part of strategic (long-term) fleet size planning [2].

In general, pilotage and tug services required by ships calling at the port can be categorized into 3 types; the first is to assist the ship when entering the port area, the second is to assist the ship when leaving the port area, and the third is to assist the ship when shifting from one location to another in the
port area. The number of tugboats required to assist one ship will depend on the size of the ship, measured in length overall (LOA). If the ship is relatively small, then the number of tugboats required is only one unit, whereas for the ship relatively large in size, the number of tugboats required is more than one unit. The problem of fleet sizing planning in the case of tugboats configurations is quite complex since it involves high uncertainty parameters such as inter-arrivals time of the demand for services, the size of the ships and the type of service required. In addition, the potential for a simultaneous arrival of demand for services, makes fleet sizing problem of the tugboats highly stochastic. For this reason, the combination of simulation and assignment model was chosen as the methodology in solving this problem.

The objective of this paper is to present a decision support methodology for strategic planning in fleet sizing problem in the case of tugboat to support port operations. The methodology includes a Monte Carlo simulation model built to describe the uncertainty of the real system behavior represented by probability distributions, whereas the assignment model built to allocate tugboats. There is a strong interdependency between strategic, tactical and operational planning levels, therefore, the decision must consider those aspects simultaneously. The methodology in this paper can provide support for port authorities or port operators in decision problems related to tugboats configurations.

2. Literatur Review

Fleet sizing is a complex problem which requires various decision, both strategic and operational point of view. Strategic decisions deal with long-term planning about maximize projected profit such as fleet size, type and composition, whereas operational decision deal with routing strategy [2]. In addition, the real-life fleet sizing problem is very depend of the many factors which are difficult to predict and makes this problem highly stochastic. The important interactions between decision fleet sizing and fleet utilisation was studied by GJ Beaujon. The author formulated a model to optimize both side of fleet size and utilisation simultaneously under dynamic and uncertain conditions [3]. Furthermore, the study of interaction between the stochastic behavior of the seaborne trade and the composition of the fleet was studied by Pantuso [4].

The shortcomings of solving fleet sizing problem by using deterministic model was studied by Ali Moradi et al with case study in surface mining operation. They found that at least there are two important shortcomings of deterministic model, namely: disregarding the effects of downstream process on the operation and ignoring the fleet management system effects. They developed an integrated simulation-optimization framework to address the fleet sizing problem and target the two shortcomings [5].

The methodology for strategic planning regarding the fleet sizing problem was studied by Fagerholt et al. The authors develop a methodology in decision support for strategic planning in tramp and industrial shipping by combining a Monte Carlo simulation and optimization. The methodology was tested on a real case for a major Norwegian shipping company [6].

Hamidreza Eskandari and Ehsan Mahmoodi have developed the methodology for fleet sizing problem in offshore industry by using simulation-based multi-objective optimization which comparing routing based on fixed schedule and routing based on platform demands. A discrete-event simulation combined with simulation-based optimization model is used to evaluate the near-optimal fleet size and composition by minimizing expected total cost and minimum platform service level as a constraint [7].

Another model for fleet sizing problem was presented by K-H Chang et al whose developed a multi-objective vehicel fleet sizing problem by integrates simulation-optimization and data envelopment analysis technique. The model was applied in designing an effective automated materials handling systems which involved uncertainty in the production process [8].

The different method for solving fleet sizing problem was presented by Halvorsen et al where their developed a voyage-based solution with the case study of Statoil – the leading operator on the Norwegian continental shelf. Their solution approach for the problem considered that all candidate voyages the the supply vessels may sail are generated a priori and the composition of the fleet and determining the voyage to sail area decided by solving a voyage-based model [9].
3. Problem definition

This paper focuses on the problem of evaluation the adequacy level of the number of tugboats to support port operations with the case study of the Tanjung Perak port area. The main reason for choosing this port is because this port is the second largest port in Indonesia after port of Tanjung Priok in Jakarta. As a large port, traffic at this port is quite heavy and if not managed properly, the potential for congestion will be very high. The second reason is that it has a channel where ships of a certain size when entering or leaving the port must be assisted by pilotage and tug services. The last one is because there are many terminals alongside the channel which make safety major issues. The whole area of the port of Tanjung Perak is depicted in Figure 1 [10].

![Figure 1. The area of port of Tanjung Perak.](image)

The provision of pilotage and tug services follows Transportation Ministerial Regulation number 57 of 2015 concerning pilotage and tug services in port area. The requirement for pilotage and tug services are regulated in Article 38 Paragraph 3 of this regulation, stating that ships with a length of 70 m – 150 m must be assisted using minimum 1 unit tugboat with a minimum power of 2.000 HP, whereas as ship with length of 150 m – 250 m assisted by minimum 2 units of tugboats with a minimum power of 6.000 HP, and ship with a length of more than 250 m assisted by minimum 3 tugboats with a minimum of 11.000 HP. The details of this regulation can be seen in Table 1 [11]:

| No. | Ship’s Length Overall | No. of Tugboat | Minimum Total Power | Minimum Bollard Pull |
|-----|----------------------|----------------|---------------------|----------------------|
| 1.  | 70 m – 150 m         | 1 unit         | 2.000 HP            | 24 Ton               |
| 2.  | 150 m – 250 m        | 2 units        | 6.000 HP            | 65 Ton               |
| 3.  | 250 m or more        | 3 units        | 11.000 HP           | 125 Ton              |

The port authority or port operator is responsible for ensuring the smoothness and safe process of the ships whether entering, leaving or shifting movements. The request for the pilotage and tug services are
independent of each other, meaning that requests can either come sequentially or simultaneously (parallel). Meanwhile, the duration of service depends on the type of service and the location of the ship. The farther the distance, the longer it will take for tugboat to be ready as it has to return to base after completing its task. In heavy traffic conditions, the possibility of not having tugboats available at the base is quite high, on the other hand, many tugboats are under utilized when the traffic is not so heavy. With these highly uncertain conditions, port authority or port operator must be able to make the right decisions regarding the planning of tugboats configurations should be owned.

Currently, the port authority of port Tanjung Perak area operates 16 tugboats with a composition of 13 owned tugs (2 of which are very old and will no longer operate) and 3 charter tugs which are about to expire, therefore, the total number of tugboats that can be fully operational in only 11 units. To maintain confidentiality, the data of 11 tugboats operated are presented with code as shown in Table 2. It is necessary to evaluate the operational performance of the pilotage and tug services with the remaining 11 tugboats and if necessary how many additional tugs are needed so that performance can run optimally.

| No. | Tugboat | Power (HP) |
|-----|---------|------------|
| 1.  | TB-01   | 2 x 2.400  |
| 2.  | TB-02   | 2 x 1.800  |
| 3.  | TB-03   | 2 x 1.000  |
| 4.  | TB-04   | 2 x 1.000  |
| 5.  | TB-05   | 2 x 1.000  |
| 6.  | TB-06   | 2 x 1.500  |
| 7.  | TB-07   | 2 x 1.800  |
| 8.  | TB-08   | 2 x 1.800  |
| 9.  | TB-09   | 2 x 1.800  |
| 10. | TB-10   | 2 x 1.300  |
| 11. | TB-11   | 2 x 1.500  |
| 12. | TB-12*  | 2 x 1.220  |
| 13. | TB-13*  | 2 x 1.220  |
| 14. | TB-14*  | 2 x 1.100  |
| 15. | TB-15** | 2 x 750    |
| 16. | TB-16** | 2 x 600    |

* chartered tugboats which are about to expire
** owned tugboats which are very old

| No. | Tugboat | Power (HP) |
|-----|---------|------------|
| 1.  | TB-01   | 2 x 2.400  |
| 2.  | TB-02   | 2 x 1.800  |
| 3.  | TB-03   | 2 x 1.000  |
| 4.  | TB-04   | 2 x 1.000  |
| 5.  | TB-05   | 2 x 1.000  |
| 6.  | TB-06   | 2 x 1.500  |
| 7.  | TB-07   | 2 x 1.800  |
| 8.  | TB-08   | 2 x 1.800  |
| 9.  | TB-09   | 2 x 1.800  |
| 10. | TB-10   | 2 x 1.300  |
| 11. | TB-11   | 2 x 1.500  |


4. Proposed method
We propose a framework, as shown in Figure 2 to evaluate fleet sizing problem which consists of two phases. In the phase I, a Monte Carlo simulation is applied to capture the behavior of the real system, whereas in the second phase, if focuses on allocation of tugboats to serve the demands generated in phase I. More details about phase I and II the framework are as follows:
Figure 2. Proposed method.

The phase I of the framework starts with the problem definition which include clear description of how real system works (business process). Next, historical data is collected which are then used to identify the behavior of the real system. Such behavior can obtained by analysing the probability distribution characteristics of several parameters including inter-arrivals time between requests, ship size and duration of services. Result of this analysis will be used to construct a simulation model by applying a Monte Carlo method. In the last stage of phase I, the model need to be verified and validated to ensure the it sufficiently represent the real system.

In the phase II, the assignment model is developed based on the business process and the regulation as shown in Table 1. Before running the assignment model, the scenarios of tugboat configurations are generated, as follows:

- Scenario 1: the number of tugboats deployed is 11 units, same as the current condition where 3 chartered tugs are not extended and 2 very old tugs are no longer operated.
- Scenario 2: the number of tugboats deployed is 14 units, 11 of which are currently owned and 3 chartered tugs are extended with the power of 2 x 1.220 HP each.
- Scenario 3: the number of tugboats deployed is 16 units, 11 of which are currently owned, 3 chartered tugs are extended and replacement of 2 old tugs with the power of 2 x 1.500 HP each.

Next, the system performance is evaluated based on the result of assignment model for each scenario. The evaluation of system performance is done by not only calculate the tugboats utilization but also the number of service requests that must wait.

5. Results and discussion

The proposed method presented in Section 4 has been tested on the real problem of pilotage and tug services faced by port authority in port of Tanjung Perak area. The characteristics of historical data and general assumption are describe in Section 5.1. This is followed by verification and validation model based on characteristics derived from historical data in Section 5.2. In the following sections 5.3 we describe an analysis of results.

5.1. Characteristics of historical data

In the period of January – September 2018, the number of pilotage and tug services reached 15,579 movements. The data shows that pilotage and tug services in port of Tanjung Perak area are dominated
by small ships group with a proportion of about 78%. It is followed by medium and large groups having a proportion of 21% and 1% respectively. The detail picture is shown in Table 3.

Table 3. Pilotage and Tug Services in Port of Tanjung Perak.

| Ship Categories       | Service (Movement) Types | Entering | Leaving | Shifting | TOTAL  |
|-----------------------|--------------------------|----------|---------|----------|--------|
| Small (70 – 150 m)    |                          | 3.711    | 4.179   | 4.271    | 12.161 |
| Medium (150 – 250 m)  |                          | 1.030    | 1.190   | 1.064    | 3.284  |
| Large (250 m up)      |                          | 49       | 49      | 36       | 134    |
| **TOTAL**             |                          | 4.790    | 5.418   | 5.371    | 15.579 |

One of the key factors in developing a model as close to the real conditions as possible is the process of identifying uncertainty parameters. In this paper, we identified three parameters that greatly affect the system performance and are stochastic in nature, namely the inter-arrival time between requests, ship size and service duration. The results of the identification of these parameters are as follows:

5.1.1. Inter-arrivals time between service requests

The inter-arrival time between service requests is not only one of the factors that determine the number of tugboats needed, but also a factor that can describe the density of a port. The inter-arrival time profile based on the historical data is depicted in Table 4.

Table 4. Profile of inter-arrival time.

| Statistical properties | Distribution: Exponential | Formula |
|------------------------|---------------------------|---------|
| Mean (hours)           | 0.3808                    | $f(x; \lambda) = \begin{cases} \lambda e^{-\lambda x}, & x \geq 0 \\ 0, & x < 0 \end{cases}$ |
| Minimum (hours)        | 0.0000                    |         |
| Maximum (hours)        | 10.8333                   |         |
| Standard deviation     | 0.4198                    |         |

It can be seen from Table 4 that minimum inter-arrival time is 0 which means that some request may come simultaneously. It is recorded that there are 2.074 requests or more than 13% of 15.579 come at the same time.

5.1.2. Ship size

As previously mentioned, ships under 70 m of LOA are excluded in this study, as they do not require pilotage and tug services. The ship size profile derived from historical data can be seen in Table 5.

Table 5. Profile of ship size.

| Statistical properties | Distribution: Gamma | Formula |
|------------------------|---------------------|---------|
| Mean (m)               | 124.58              | $f(x) = \frac{x^{\alpha-1}e^{-x/\beta}}{\beta^\alpha \Gamma(\alpha)}$ |
| Minimum (m)            | 70.00               |         |
| Maximum (m)            | 268.80              |         |
| Standard deviation     | 40.85               |         |
5.1.3. Service time duration
As the duration of service time are categorized into three groups according to the type of services, namely entering, leaving and shifting movements, the profile of service time duration is also categorized into three groups. The profile of each groups are as follows:

### Table 6. Profile of service time duration.

|                      | Entering movements | Leaving movements | Shifting movements |
|----------------------|--------------------|-------------------|-------------------|
| **Statistical properties** | Distribution: Lognormal | Formula | |
| Mean (hours) | 0.689 | $f(x) = \Phi \left( \frac{\ln(x) - \mu}{\alpha} \right)$ | |
| Minimum (hours) | 0.150 | | |
| Maximum (hours) | 4.500 | | |
| Standard deviation | 0.194 | | |
| Mean (hours) | 0.683 | $f(x) = \Phi \left( \frac{\ln(x) - \mu}{\alpha} \right)$ | |
| Minimum (hours) | 0.133 | | |
| Maximum (hours) | 5.417 | | |
| Standard deviation | 0.195 | | |
| Mean (hours) | 0.686 | $f(x) = \Phi \left( \frac{\ln(x) - \mu}{\alpha} \right)$ | |
| Minimum (hours) | 0.117 | | |
| Maximum (hours) | 4.000 | | |
| Standard deviation | 0.184 | | |

5.2. Model verification and validation
Separation between model verification and validation is very difficult to do because these two processes are closely related and often use the same technique for both. A model can be said verified if the behavior generated by the model is similar to the actual behavior. To verify the model, we use certain condition where the result can be analyzed analytically and compare them with those produced by the model. On the other hand, validation is the process of comparing the representation of a model to the real system. If the comparison is true (with tolerable error), then it is valid.

For validation, the model is run using the aforementioned distribution of 8 months length data and then compare the results with the real data. The results as can be seen in Table 7 shows that the difference between real data and simulation result is only 0.07% which is substantially low. Therefore, we can proceed the model with the characteristics as previously mentioned to predict the performance of the system by applying some scenarios.

### Table 7. Comparison between data and simulation result.

| Ships Category | Service (movement) types | (a) Historical data. | (b) Simulation result. |
|----------------|--------------------------|----------------------|------------------------|
|                | Entering | Leaving | Shifting | TOTAL | Entering | Leaving | Shifting | TOTAL |
| Small          | 3.711    | 4.179   | 4.271    | 12.161 | 3.601    | 4.261   | 4.301    | 12.163 |
| Medium         | 1.030    | 1.190   | 1.064    | 3.284  | 1.059    | 1.199   | 1.031    | 3.289  |
| Large          | 49       | 49      | 36       | 134    | 60       | 43      | 35       | 138    |
| TOTAL          | 4.790    | 5.418   | 5.371    | 15.579 | 4.720    | 5.503   | 5.367    | 15.590 |
5.3. Analysis of results
By implementing the probability distribution as presented in previous stage, demand estimation for pilotage and tug services for the next few years can be done by assuming a growth of 3%-4% per year.
In this paper, we estimate the demand for 2021 or three years from the base year. By replicating the simulation process 30 times, the estimation of demand for pilotage and tug services are as follows:

| Table 8. Projected demand in 2021. |
|-----------------------------------|
| # Requests | Mean (8.272) | Minimum (12%) | Maximum (50%) | Std (8%) |
| Total      | 27.091       | 26.872        | 27.262        | 108      |
| Entering   | 8.326        | 8.227         | 8.481         | 83       |
| Leaving    | 9.416        | 9.246         | 9.532         | 84       |
| Shifting   | 9.350        | 9.221         | 9.508         | 95       |

The assignment model is then used to allocate tugboats in each scenario to evaluate the performance of the system based on the demand projected. The evaluation of system performance is carried out by taking into account two aspects which include the number of requests that must be queued and the utilization of tugboats. In this paper, the system performance is said to be good if there is no queuing requests and the utilization of tugboats is high. The replication process of this assignment model is 30 times, same as the replication of simulation for demand estimation. The results from the methodology provided important decision support for strategic fleet sizing planning as shown in Table 9 - Table 11.

| Table 9. Results of scenario 1. |
|-------------------------------|
| (a) Number of queue.          |
| Mean | Min | Max | StD |
| 401  | 157 | 472 | 84.75 |

| (b) Tugboats utilization.     |
|-------------------------------|
| TB-1  | TB-2  | TB-3  | TB-4  | TB-5  | TB-6  | TB-7  | TB-8  | TB-9  | TB-10 | TB-11 |
| Mean  | 25%   | 25%   | 26%   | 41%   | 43%   | 42%   | 19%   | 19%   | 18%   | 17%   |
| Min   | 21%   | 21%   | 17%   | 33%   | 37%   | 37%   | 12%   | 9%    | 12%   | 13%   |
| Max   | 30%   | 29%   | 31%   | 46%   | 49%   | 51%   | 32%   | 35%   | 34%   | 33%   |

| Table 10. Results of scenario 2. |
|----------------------------------|
| (a) Number of queue.             |
| Mean | Min | Max | StD |
| 9    | 4   | 15  | 3.83 |

| (b) Tugboats utilization.        |
|----------------------------------|
| TB1    | TB2    | TB3    | TB4    | TB5    | TB6    | TB7    | TB8    | TB9    | TB10   | TB11   | TB12   | TB13   | TB14   |
| Mean   | 18%   | 17%   | 19%   | 30%   | 29%   | 32%   | 30%   | 33%   | 32%   | 17%   | 16%   | 1%    | 8%    | 13%    |
| Min    | 12%   | 3%    | 12%   | 25%   | 14%   | 25%   | 18%   | 26%   | 18%   | 10%   | 13%   | 1%    | 6%    | 6%     |
| Max    | 21%   | 22%   | 24%   | 37%   | 46%   | 46%   | 38%   | 36%   | 39%   | 32%   | 21%   | 1%    | 14%   | 22%    |

| Table 11. Results of scenario 3. |
|----------------------------------|
| (a) Number of queue.             |
| Mean | Min | Max | StD |
| 1    | 0   | 2   | 0.67 |

| (b) Tugboats utilization.        |
|----------------------------------|
| TB1    | TB2    | TB3    | TB4    | TB5    | TB6    | TB7    | TB8    | TB9    | TB10   | TB11   | TB12   | TB13   | TB14   | TB15   | TB16   |
| Mean   | 16%   | 15%   | 14%   | 26%   | 24%   | 25%   | 26%   | 24%   | 28%   | 28%   | 26%   | 1%    | 6%    | 6%    | 11%    | 11%    |
| Min    | 14%   | 3%    | 3%    | 24%   | 13%   | 13%   | 14%   | 14%   | 26%   | 26%   | 17%   | 1%    | 6%    | 6%    | 11%    | 11%    |
| Max    | 18%   | 18%   | 18%   | 28%   | 28%   | 28%   | 29%   | 30%   | 29%   | 30%   | 32%   | 1%    | 7%    | 7%    | 12%    | 12%    |
The results provided important decision support for strategic fleet sizing planning. It is showed that increasing the number of tugboats would reduce the number of queues almost exponentially, but on the other hand it also reduce tugboats utilization linearly. This indicates that the trade-off between the impact of additional tugboats on the number of queues and tugboats utilization must be carefully considered in the decision process.

In addition, the results also indicate that the possibility of increasing tugboats utilization without increasing the number of queues is difficult to reach. This is because the number of service request that come simultaneously is quite large, between 13% - 15%. Another factor that makes this objective difficult to reach is because the average inter-arrival time between requests is smaller than the average of the service time, which means that there are new requests before the tugboat has finished carrying out the task it is running.

The results is also showed that in the case of port of Tanjung Perat area, scenario 2 gave the best result although there are still some request to wait. This decision is based on the results which show that even though there are still any queues, but the number of queues is tolerable, where the average number of queues is 9 requests which is equivalent to 0.034% of the total requests.

6. Conclusion
In this paper we have presented a methodology to support the decision of tugboats configuration for pilotage and tug services in port operations. Our proposed methodology combines a Monte Carlo simulation and fleet assignment model, where a Monte Carlo simulation is built to generate request types, ships size and duration of services which are then applied in assignment model. There are two major advantages of the method we proposed:

- The model of Monte Carlo simulation makes it possible to deal with the stochastic aspects in the pilotage and tug services in a port with a quite precision
- The assignment model is flexible in the sense that it can easily change the tugboats configurations to provide decision support for strategic fleet sizing planning.

One main disadvantage of this methodology is that the process requires a lot of computer time due to many runs of the model that must be made to provide trustworthy results. The requirement for a relatively large amounts of high quality data to generate probability distributions for the parameters of the real system is another drawback of this methodology. However, we believe that the processing time is not a big deal when compared to the important important strategic decisions that may have an impact several year ahead in time.

We have tested the methodology on a actual pilotage and tug services at port of Tanjung Perak area and proved to provide valuable decision support on important strategic fleet sizing problems faced by port authority or port operator. The issue of cost has not been considered in this methodology, this is an interesting topic for future research. Another interesting area for future work is how to make processing time faster.

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