The investigation of life cycle costs of Mobile Harbour Crane: a case study in Berlian Terminal at Tanjung Perak Seaport Surabaya

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Abstract. Cost is one of the important components that may not be separated in loading and unloading operations, as tariff setting of terminal operation depends on the level of cycle costs implemented. During the life cycle, from the planning to operational stages, every stage is closely related to the cost component. If it is not well managed, it may consequently generate higher costs in the loading and unloading operation. The equipment focused of this research is Mobile Harbor Cranes (MHC) which are being operated in Berlian Terminal, Tanjung Perak port, Surabaya. The main problem as a main concern of this research is how to correlate the allocation of cargo handling equipment with the cost planning during the lifetime of the equipment. Particularly to clearly define the level of costs expended in accordance with the time and workload of the equipment. The research aims of this research, therefore, is to evaluate and optimize the cost cycle value of MHC based on its energy usage applying linear programming. As the result, the research finds that MHC maintenance cost were higher than operational cost. To achieve more efficient maintenance and operational costs, 11 scenarios of energy usage were applied to have a balance life cycle cost arrangement.

1. Introduction

Container transportation has a large influence and role in the global economy with about 90% of global transportation carried out by containers. Ports are a core component of the international supply chain and play an important role in the regional economy. Further, regional development is directly related to the ability of the seaport terminal to adapt the emerging challenges [1,2]. Berlian Container Terminal, known as BJTI Port, is one of the port operators that performs as an emerging domestic container terminal at Tanjung Perak Seaport, Surabaya – Indonesia. The main handling equipment operating at Berlian Terminal is Mobile Harbor Crane (MHC). The operation of equipment at Berlian Terminal may not be separated from the cost component. Costs in the loading and unloading process are allocated according to the services executed by terminal operator particularly on loading and unloading operations of the MHCs. During the MHC’s cycle, from planning stage to operational stage, all are closely related to the cost components. The cost components in the MHC life cycle comprise the initial capital, maintenance, and operational costs of equipment, and even replacement costs.

The problem is that there was still a lot of cargo handling equipment including the planning of equipment cost was not well-defined resulting miscalculation between time and workload of the equipment. Therefore, to calculate actual cost expended based on time and workload, this research uses...
Life Cycle Cost (LCC) approach to rational the quantity and stage of cost items based on time period. The MHC life cycle is further used as one component of the equipment management process and makes it possible to have a better improvement and usage based on the economic life of a particular equipment. The life cycle analysis in addition also may assist the decision to repair, remodel, or replace equipment with the combination cost function of ownership and operation. At the end, the life cycle analysis may combine the variables of economic lifetime, replacement time and cost.

2. Basic Assumptions of the Research
The focus of the research is to apply the life cycle cost approach in the operation handling equipment taking Berlian Terminal as the location of the research.

2.1 Berlian Terminal
Berlian Terminal has container yard (CY) with 58,110 m² with its capacity of 8,316 TEUs, (see Figure 1 shows the lay-out of Berlian Terminal). The Berlian terminal has 20 CY blocks that serve as temporary storage areas for containers coming from outside the terminal to wait to be loaded onto the ship, or vice versa temporary storage areas for containers that have just been unloaded from the ship to be transported by trucks going outside the terminal.

![Figure 1. Layout of Berlian terminal [3]](image)

Berlian Terminal has a total berth length of 1,620 m, consisting of West Berlian terminal with length of 700 meters, the North Berlian terminal with length of 140 meters and the East Berlian Terminal with length of 780 meters which are mainly served by Mobile Harbor Crane (MHC) [3].

2.2 Mobile Harbour Crane
MHC is mounted on a rubber-tyre chassis combined with existing installations to increase the operational capacity. MHCs in Berlian Terminal are used as the back-up for conventional berth cranes, that handle special loads and when additional terminal capacity is required. In Berlian Terminal, MHyS are also used to replace conventional cranes due to its flexibility and less investment compared to others.
particularly in handling all forms of cargo such as containers (up to post Panamax ships), bulk, general and project cargoes (machines) [4].

The lifting gear can be easily interchanged including grabs, spreaders, C-hooks, slings, chains, magnets and lifting beams. These cranes offer maximum flexibility, able access any location within the terminal and lifting capacities of up to 200 tons. An anti-sway system is usually installed to reduce the sway on the spreader. Usually a diesel-electric generator is fitted within the crane to allow it to operate autonomously, however, where available, an external power source (shore power) can usually be used. On MHCs there has a small space available inside the electric cabin by which hoisting and slewing movements are usually driven by DC drives and motors as they require less space. Two driver cabins are usually installed, the first in a high position on the tower to ensure excellent visibility of the ship’s cargo and the second on the chassis to ensure an excellent view when the crane is moving inside the terminal. Figure 2 illustrates an example of MHC.

![Figure 2. Mobile harbour crane [4]](image)

### 2.3 Life Cycle Cost Analysis (LCCA)

Life cycle cost analysis (LCCA) is a tool that can help analyze the overall economic sustainability of assets. LCCA consists of life-cycle costs, equipment decision procedures, replacement analysis, and replacement models [5,6]. The decision to repair, remodel, or replace equipment is decided based on a function of ownership and operation costs. LCCA has a few components, namely acquisition costs, operating costs, and maintenance costs. Ownership costs will include initial costs, depreciation, insurance, taxes, storage, and investment costs. Figure 3 presents a life cycle cost chart which contains component costs and their fluctuation as function of the asset life cycle.

![Figure 3. Life cycle costs chart [6]](image)

### 2.4 Cost Component

LCC is a planned approach, and therefore all life cycle cost elements are related to the function and performance of an equipment or item. The results of this life cycle cost analysis can be considered as a reference to the management and a decision-making process depend on several available options [7,8].
One way to do a life cycle cost analysis is to develop a detailed model of structured costs and the selection of cost components. The results of LCC are the estimated life cycle costs for the next few years until the economic life of the equipment or asset come to an end.

2.4.1 Initial costs
Initial costs or capital costs refer to the funds used by the company to purchase, increase, or maintain long-term assets to increase the efficiency or capacity of the company.

2.4.2 Operating costs
Operating costs are costs in the form of spending money to carry out basic activities, in the current case is loading and unloading operations. In this case, the operating costs is divided into two parts: energy costs and labor costs.

2.4.3 Maintenance costs
The maintenance cost itself is the cost provided to maintain MHC's performance so that it can carry out loading and unloading operations as efficiently and effectively as possible. Here are some types of maintenance actions taken by Berlian Terminal to maintain the performance of MHC maintenance consists of preventive maintenance corrective maintenance and breakdown maintenance.

3. Methods
The research process begins with identifying problems followed by literature study in relation to LCCA and handling equipment. After the literature study is accomplished [5,6,7,8,9,10], it is then continued by determining the required data to support the problem-solving process in this research.

3.1 LCC Data
The main object of this research is MHC which is being utilized in Berlian Terminal. Data is collected mainly in the basis of primary and secondary data. Primary data is obtained directly from interviews. While secondary data is gained from the Berlian Terminal office such as throughput, berth dimensions, investment costs, insurance costs, operating costs, maintenance costs and disposal fees.

For the research, it is assumed that cargo handling time taken at 10,686.6 hours accumulatively collected in 2017 to 2018. In addition, from the data, it is noted that in the period of November 2017, there was a significant increase of total life cycle costs by 77% from the previous month. This was due to higher maintenance cost of wire rope changes which accounted for 98% of the total maintenance costs at that time.

Figure 4. LCC of MHC 03
Further, in July to December 2018, maintenance costs incurred, and total throughput tend to be stable. This indicated that when MHC 03 handles 6,000 – 7,000 box containers every month, the maintenance costs incurred tend to be stable, as shown in Figure 4.

3.2 Linear Programming
Linear programming in the current research is applied in the process of optimizing the life cycle costs of MHC. The analysis is first formulated in the form of a mathematical model. This mathematical model is obtained based on the arrangement of problems that are formed more simply in the form of objective functions to minimize costs and boundary functions.

3.2.1 Mathematical model
The mathematical model of a problem is the formulation of a problem in the form of equation or mathematical function. The mathematical formulation of the equation is an objective function related to the process that occurs in the use of MHC to achieve the optimal operating costs of the MHC. If linear programming problems can be optimized, the optimal value will occur in one region node that represents a set of feasible solutions [5,6,7].

3.2.2 Objective function
The objective function for the current study is expressed as:

\[ Z = \min [(t_1 \cdot c_1) + (t_2 \cdot c_2) + \ldots + (t_n \cdot c_n)] \]  

where:
- \( t \) = MHC operating time
- \( c \) = Total costs incurred by each MHC
- \( n \) = Number of MHC

\[ t = \frac{T}{(p_1 \cdot m_1) + (p_2 \cdot m_2) + \ldots + (p_n \cdot m_n)} \]  

where:
- \( p \) = Performance of each type of MHC
- \( m \) = Number of each type of MHC

\[ C = C_o + C_m \]  

where:
- \( C \) = Total costs incurred by each MHC
- \( C_o \) = Operational costs for each MHC
- \( C_m \) = Maintenance costs for each MHC

\[ C_o = C_{B} + C_{L} + n_B + n_L \]  

where:
- \( C_{B} \) = Operational costs if use fuel for each MHC
- \( C_{L} \) = Operational costs if use electricity each MHC
- \( n_B \) = Operational costs if use fuel for each MHC
- \( n_L \) = Operational costs if use electricity each MHC

3.2.3 Constraints
Constraints may refer to capacity, availability, resources, technology, etc. This reflects the limitations of the environment in which MHC operates. Each combination of values that applies to decision variables form the solution to the problem. When these values meet problem constraints, the solution is a feasible solution [9,10].

\[ 13 = n_{TB} + n_{TU} + n_{TT} \]  

The constraint is the number of MHCs per type. At Berlian Terminal there are available MHC types of HMK 4406 MAN totally 5 units, HMK 4406 totally 4 units, and HMK 5506 Cummins totally 4 units.
Constraint is given so that the number of MHCs assigned to the entire berth the same as the available MHC.

\begin{align}
1 & \leq n_{HB1} + n_{HU1} + n_{HT1} \leq 5 \\
1 & \leq n_{HB2} + n_{HU2} + n_{HT2} \leq 4 \\
1 & \leq n_{HB3} + n_{HU3} + n_{HT3} \leq 4 \\
\end{align}

The number of MHC at each determined by division based on the ratio of the berth length determined in the calculation of Table 1.

\begin{align}
n_{TB} & \leq 5 \ ; \ n_{TB} = n_{HB1} + n_{HB2} + n_{HB3} \\
n_{TU} & \leq 2 \ ; \ n_{TU} = n_{HU1} + n_{HU2} + n_{HU3} \\
n_{TT} & \leq 6 \ ; \ n_{TT} = n_{HT1} + n_{HT2} + n_{HT3} \\
\end{align}

To prevent the linear programming model from giving a negative result to the number of MHC assignments, then the following non-negative constraints are applied:

\begin{align}
n_{TB} & \geq 1, \ n_{TU} \geq 1, \ n_{TT} \geq 1 \\
n_{HB1} & \geq 0, \ n_{HB2} \geq 0, \ n_{HB3} \geq 0 \\
n_{HU1} & \geq 0, \ n_{HU2} \geq 0, \ n_{HU3} \geq 0 \\
n_{HT1} & \geq 0, \ n_{HT2} \geq 0, \ n_{HT3} \geq 0 \\
\end{align}

where:

- $n_{TB}$ = number of MHC at West Berlian Terminal
- $n_{TU}$ = number of MHCs at North Berlian Terminal
- $n_{TT}$ = number of MHC at East Berlian Terminal
- $n_{HB1}$ = total MHC type HMK 4406 MAN at West Berlian
- $n_{HB2}$ = total MHC type HMK 4406 Cummins at West Berlian Terminal
- $n_{HB3}$ = total of MHC type HMK 5506 Cummins at West Berlian Terminal
- $n_{HU1}$ = total MHC type HMK 4406 MAN at North Berlian Terminal
- $n_{HU2}$ = total MHC type HMK 4406 Cummins at North Berlian Terminal
- $n_{HU3}$ = total MHC 550K Cummins type at North Berlian Terminal
- $n_{HT1}$ = total MHC type HMK 4406 MAN at East Berlian Terminal
- $n_{HT2}$ = total MHC type HMK 4406 Cummins at East Berlian Terminal
- $n_{HT3}$ = total MHC type 5506 Cummins type at the East Berlian Terminal

Table 1 is the results of the optimization of MHC configuration at each berth. The optimization is resulting in the optimum number of crane at each berth.

| Berth            | Type of MHC  | Number of Crane |
|------------------|--------------|-----------------|
| West Berlian     | HMK 4406 MAN | 1               |
|                  | HMK 4406 Cummins | 0              |
|                  | HMK 5506 Cummins | 4              |
|                  | HMK 4406 MAN | 3               |
| East Berlian     | HMK 4406 Cummins | 3              |
|                  | HMK 5506 Cummins | 0              |
|                  | HMK 4406 MAN | 1               |
| North Berlian    | HMK 4406 Cummins | 1              |
|                  | HMK 5506 Cummins | 0              |
4. Results and Discussions
After involving and analyzing all elements of the MHC life cycle with various costs during 2017-2018 and to update the same as the present value, the results obtained are reflected in the followings.

4.1 Comparison Between Cost and Throughput
Life cycle cost is a tool to help increase MHC work costs that support options where there are alternative ways to achieve goals and where alternatives are different, not only in initial costs (initial costs) but also in operational costs and maintenance costs [8]. The Costs expended for MHC operations and throughput which is the revenue generated by one of the cranes, as shown in Figure 5, the total costs for operating HMC tend to be unstable when compared to the revenue (throughput) generated.

![Figure 5. Comparison between cost and throughput of the terminal during 2017-2018](image)

There are costs that have the most drastic increase or decrease. This is caused by the act of maintenance or replacement of components that have a greater cost. But with the operation of electricity usage, the overall costs of the MHC cycle are smaller and maintenance actions also take longer which causes the cycle costs to be lower. It can be concluded that the choice of energy use can have a large impact on the value of the costs incurred.

4.2 Optimization Results
Based on the results of linear programming using an appropriate solver, the MHC configuration in each berth is obtained as the Table 2. There are 13 MHC operating in Berlian Terminal. MHC 03, 04, 05, 09 and 10 are HMK 4406 types which use MAN type engines where the energy source is diesel fuel and is not equipped with electrification facilities. MHC 13, 14, 15, 16 and 17 are HMK 4406 types that use Cummins type engines where the energy source is diesel fuel and has been equipped with electrification facilities. while MHC 18, 19, and 20 are HMK 5506 types that use Cummins type engines where the energy source is diesel fuel and has been equipped with electrification facilities, but has a longer range.

| Berth          | Type of MHC         | Total Operational Cost (IDR) | Total Maintenance Cost (IDR) |
|----------------|---------------------|-----------------------------|-----------------------------|
| West Berlian   | HMK 4406 MAN        | 2,871,864,641               | 1,764,035,333               |
|                | HMK 4406 Cummins    | -                           | -                           |
|                | HMK 5506 Cummins    | 2,461,598,263               | 7,086,925,333               |
|                | HMK 4406 MAN        | 8,326,521,732               | 5,292,106,000               |
|                | HMK 4406 Cummins    | 1,784,254,657               | 5,183,194,000               |
|                | HMK 5506 Cummins    | -                           | -                           |
| East Berlian   | HMK 4406 MAN        | -                           | -                           |
|                | HMK 4406 Cummins    | -                           | -                           |
The operation and maintenance costs of the harbor mobile crane with the scenario of using 100% electricity consumption for MHC 13 to MHC 20 and using 100% fuel for MHC 03 to MHC 10. In this case, 11 operating scenarios (see Table 3 below) are considered as recommended by [11] based on the level of usage of both electricity and fuel when MHC operates with the aim of finding the most minimal costs. Scenario 1 is an energy use scenario with a composition of 100% fuel energy usage and 0% electricity usage, scenario 2 uses a composition of 90% fuel usage and 10% electricity usage and so on until scenario 10 which consists of a composition of 10% fuel energy usage and 90% electricity usage. For scenario 11 consisting of 5% fuel energy use and 95% electricity. Scenario 11 is made based on the level of blackouts that occur at the diamond terminal and the potential for MHC traveling movement to the other side of the berth.

**Table 3. Scenario of energy usage**

| Scenario | Fuel Usage (%) | Electricity Usage (%) |
|----------|----------------|-----------------------|
| 1        | 100%           | 0%                    |
| 2        | 90%            | 10%                   |
| 3        | 80%            | 20%                   |
| 4        | 70%            | 30%                   |
| 5        | 60%            | 40%                   |
| 6        | 50%            | 50%                   |
| 7        | 40%            | 60%                   |
| 8        | 30%            | 70%                   |
| 9        | 20%            | 80%                   |
| 10       | 10%            | 90%                   |
| 11       | 5%             | 95%                   |

In this case, 11 operating scenarios are based on the level of usage of both electricity and fuel when MHC operates with the aim of finding the most minimal costs (see Figure 6). Scenario 1 is an energy usage scenario with a composition of 100% fuel energy use and 0% electricity; scenario 2 with the composition of 90% fuel use and 10% electricity and so on until scenario 10 which consists of a composition of 10% fuel energy use and 90% electricity use. Finally, scenario 11 taking 5% fuel energy use and 95% electricity. In addition, scenario 11 is based on the level of blackouts that occur at the terminal including the potential for MHC traveling movement to the other side of the berth.

**Figure 6. Total cost of each scenario**
The higher the electricity consumption, the lower the operating value and the resulting maintenance costs. With the use of electricity, it will affect the life cycle value of an HMC to be lower. The research chose scenario 11 at a minimum cost of IDR. 40,773,211,000 (also have considered inflation, interest rates and exchange rates of USD 1.0 equivalent to IDR 14,225). The analysis also recommends the 11th scenario as the optimized plan due to several factors. This also fulfills the requirement of HMC using fuel power sources from the existing engine to travel to the side of the pier and the possible impact of external factors such as power outages by electricity providers.

5. Conclusions
The research has been conducted with regards to the operations of MHC in Berlian Terminal of Tanjung Perak Seaport, Surabaya. The outcomes of the research could be concluded as follows:

1. Given the existing electricity usage, the overall cost of the MHC cycle is smaller and maintenance measures also take longer, hence causes the cost cycle to be lower. It can be concluded that the selection of energy use can have a major impact on the value of the costs incurred. After the costs of all MHCs are accumulated, the costs are directly proportional to the amount of throughput produced, which means the amount of cost increases along with the amount of increased container throughput generated.

2. There are 11 recommended operating scenarios for the MHC based on energy usage. These scenarios aim to find optimal operating costs and maintenance costs. Based on the results of optimizing the use of MHC, including 5 MHCs that are operated at the West Berlian berth with each MHC operated for 5,218.3 hours each year, including 6 MHCs operating in the Eastern Berlian berth with each MHC operating for 4,956.3 hours each year; and there are 2 MHCs operated on the Northern Berlian berth with each MHC operated for 2,668 hours in one year. Scenario 11 was chosen to optimize life cycle costs by using 5% fuel energy and 95% electricity with lower operating and maintenance costs at IDR 40,773,211,000 (USD 2,866).

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