Research Article

Life Cycle Cost Analysis of Ashore Marine Engine Room

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This paper aims to present a method for comparing decision options for the ashore marine engine room. Based on the life cycle cost system, the life cycle stages are divided into design, acquisition, installation, operation, maintenance, and scrapping. A model of the life cycle cost of ashore marine engine room considering the time value of money was developed, and a calculation method for sensitivity analysis was developed. Regarding the actual case, the life cycle cost of the two options was estimated, the sensitivity of the cost of the two options was analyzed, and control recommendations were made. The results show that Option 2, with the highest initial investment, is the optimal solution, attributed to using an advanced two-stroke diesel engine with reduced operation and maintenance costs. This will be useful for reference by maritime academies.

1. Introduction

With the rapid development of maritime education, more attention is paid to the ashore marine engine room. Ashore marine engine room referred to the engineering of the power equipment and systems necessary for constructing ships with navigational functions onshore, a complex system, a wide range of equipment, and expensive characteristics. Since it was installed ashore, the main propulsion unit was loaded and unloaded by a hydro dynamometer instead of a propeller. The hydro dynamometer checked the propulsion characteristics of the main propulsion unit. Facing such a significant investment, high technology, and complex system, how to build a high-quality ashore marine engine room, how to effectively control the cost of ashore marine engine room project, improve the efficiency of the use of funds, and strengthen the cost control of ashore marine engine room project, would be an actual problem that the maritime higher education institutions need to face. Life cycle assessment (LCA) and life cycle cost (LCC) originated in the US military. It was mainly used in the development and procurement of military equipment, where products have long life cycles, high material losses, and high maintenance costs. Colangelo et al. [1] designed a hydraulic pipe made of geopolymer mortar as a prototype. A detailed comparative environmental assessment analysis of the unreinforced and reinforced geopolymer prototype was performed using a life cycle assessment (LCA). The results show that the advantages of geopolymers make them an effective alternative to traditional adhesives in many industrial environments and enable useful artifacts in hydraulic engineering. Islam et al. [2] reviewed the life cycle assessment (LCA) and life cycle cost (LCC) influencing factors for residential buildings. They found that the findings of LCA and LCC methods have been determined by the assumptions and system boundaries of building type, scope, and construction technology. Dwaikat et al. [3] studied the life cycle cost analysis and life cycle budgeting of green buildings. This study found that the future of green buildings was approximately 3.6 times their initial design and construction cost. Energy cost was weighted at 48% of the total life cycle budget of the building. The study also found that reducing the energy consumption of green buildings was the most influential factor in reducing their total life cycle cost. Moreau and Weidema [4] discuss the structure of the calculation of the environment in life cycle cost. They define a precise measure that environmental life cycle cost in practice means the sum of the added value of each activity of each participant in the product life cycle, including the internalization of foreseeable future externalities regarding the decision. As an advanced engineering management idea, life cycle cost analysis was widely used in the engineering field, while much research has been done in engineering project decisions.
Val and Stewart [5] analyzed the life cycle cost of reinforced concrete structures in the marine environment. The life cycle cost analysis results can be used to select the best decision for improving the durability of reinforced concrete structures in the marine environment, including stainless steel reinforcement. Colangelo et al. [6] applied the life cycle assessment (LCA) method to analyze the environmental impact of five concrete mixes with different amounts of recycled coarse aggregate and natural coarse aggregate (0%–30%–50%–70%–100%). The results indicated that the environmental impact of recycled coarse aggregate mixes was better than that of natural coarse aggregate mixes, with increasing amounts of recycled coarse aggregate being more effective. Fang et al. [7] developed life cycle assessment (LCA) as a decision support tool for wastewater resource recovery technologies. Studies have shown that life cycle assessment (LCA) is increasingly being used in wastewater treatment, focusing on identifying environmental trade-offs of current technologies. He et al. [8] propose a decision support framework that can identify the primary life cycle economic, social, and ecological impacts of road projects by integrating life cycle assessment and life cycle cost analysis to identify the most appropriate project options. Ristimaeki et al. [9] studied the design of an energy system for a new residential area by combining life cycle costing and life cycle assessment. The results showed that the design solution with the highest initial investment was the most feasible from a life cycle perspective. This study further strengthens the link between cost savings and carbon emission reductions in a life cycle context. As a result, sound economic and environmental design decisions can be identified by implementing LCC and LCA analysis at an early design stage. Life cycle assessment (LCA) and life cycle cost (LCC) played a significant role in decision making for onshore projects, and for the marine engineering sector, research was also carried out.

Bilgili [10] compared alternative marine fuels to analyze which are more environmentally efficient from a life cycle perspective. Biogas, DME, ethanol, LNG, LPG, methanol, ammonia, and biodiesel were identified as alternative fuels and assessed for their environmental damage over the life cycle. Laura and Vicente [11] analyzed the life cycle cost of floating offshore wind farms. There were six stages: definition, design, manufacture, installation, development, and dismantlement. These costs can be subdivided into different subcosts to obtain the critical variables for operating the life cycle cost. Gualeni et al. [12] developed and applied a life cycle performance assessment tool for ship maintenance. They concluded that ships were one of the most complex systems in the world. It was necessary to compare different design options regarding environmental performance, construction, and operating cost throughout the ship’s life cycle in the early design phase. Cucinotta et al. [13] evaluated two various engines for life cycle on two sister cruise ships, with a conventional diesel-mechanical system and an LNG system. The two configurations were analyzed in 17 different impact categories regarding climate change, human health, resource consumption, and ecosystems.

Much of the research has been focused on onshore engineering and offshore marine engineering. The ashore marine engine room has both the characteristics of onshore engineering and marine engineering. However, few studies have been carried out on the life cycle cost of ashore marine engine rooms. Based on the life cycle cost theory (Figure 1), this study establishes a life cycle cost model for ashore marine engine room considering the time value of money and the calculation method of sensitivity analysis to find out the sensitive factors affecting the cost of the program and proposes control recommendations. Figure 2 shows offshore vessels, Figure 3 shows ashore marine engine room 1, and Figure 4 shows ashore marine engine room 2.

2. Modeling

The life cycle of an engineering project could be divided into the various life stages of buildings: construction, operation, maintenance, and scrap [14]. Meanwhile, the life cycle of an ashore marine engine room includes project design, equipment acquisition, civil works, installation, operation, and scrap. Environment [15], economics [16], and other issues were brought to the attention of the life cycle study. The methodology for this study is cost breakdown structure analysis [17], which identifies major costs and subcost. This article defines the cost incurred at each stage: design cost, acquisition cost, installation cost, operation cost, maintenance cost, scrap cost, and environmental cost. The formula for calculating the life cycle cost of an ashore marine engine room without taking into account the time value of money is [18]

\[
LCC = \sum (C_i + LC_E). 
\]

LCC refers to the economic cost evaluation results obtained using the LCC method, representing the internal cost, including design, acquisition, and installation costs. \(LC_E\) is the external cost, including operation, maintenance, scrap, and environmental costs. The following symbols indicate cost: DC means design cost, AC means acquisition cost, IC means installation cost, OC means operation cost, MC means maintenance cost, SC means scrap cost, and EC means environmental cost. Table 1 shows the cost elements.

The goal of constructing ashore marine engine rooms in maritime higher education institutions is to improve education, teaching, and research and train more marine professionals. The life cycle cost technique for decision-making is based on the same benefit scenario and the preference of different options. It provides a reference for decision-makers by calculating the difference in life cycle cost of the options.

2.1. Life Cycle Modification. There are different design solutions for engineering projects with varying cycles of life. When selecting solutions for different life cycles, the other life cycles must be modified and measured uniformly to ensure that the chosen indicators are reasonable [19]. The answers are as follows.

1. Firstly, the least common multiple of the life cycles of the different options is used as the final analysis year.
to derive the life cycle cost of the various options. Finally, the analysis is judged.

(2) The cost is calculated based on the actual life cycle of the different options, and then the cost is divided into each year to obtain the annual average cost \( \text{LCC}_a \). Finally, the \( \text{LCC}_a \) is analyzed.

\[
\text{LCC}_a = \frac{\text{LCC}}{T} \tag{2}
\]

where \( \text{LCC} \) is the actual life cycle cost value of the program, \( T \) is the basic life cycle of the program, and \( \text{LCC}_a \) is the average of the life cycle cost of the program.

2.2. Annual Interest Rate Modification. The overhead costs are incurred in the ashore marine engine room engineering design, construction, operation, and scrap phases. The time of each phase is a dynamic influence, and the time value of money cannot be ignored for a more accurate calculation. When analyzing cost, the monetary value needs to be converted to the same time point. Future value is the conversion of cash into matching funds at a future point [20].
where $V_0$ is the present value of the currency, $R$ is the annual interest rate, $n$ is the length of the deposit, and $V$ is the future value after $n$ years.

Present value is the conversion of cash (currency) at a future point into matching funds at the current point in time.

$$V_n = V_0 \times (1 + R)^n,$$

where $V_0$ is the present value of money, $R$ is the annual interest rate, $n$ is the number of years of deposit, and $V_n$ is the future value after $n$ years. $(1 + R)^{-n}$ is the present value factor.

2.3. Inflation Rate Modification. Due to the high cost of ashore marine engine room projects, such as the diesel engines in main power propulsion units that can cost millions [21], the time value of money must be considered when costing them. Inflation has a significant impact on expensive equipment with a long lifecycle. Among other things, the rate of inflation also affects the interest rate. Real interest rate is

$$i_R = \frac{1 + i_N}{1 + i_F} - 1,$$

where $i_F$ is the inflation rate, $i_N$ is the nominal interest rate, and $i_R$ is the real interest rate.

2.4. Payment Method Modification. Because different payment methods result in different time values of money, a modification of the payment method is required.

The formula for calculating the present value of a lump-sum payment is

$$P = F (1 + i)^{-n},$$

where $P$ is the present value, $F$ is the future value, $i$ is the nominal interest rate, and $n$ is the year in which it occurs.

The formula for calculating the present value of the equal payment is

$$P = A \left( \frac{(1 + i)^n - 1}{i(1 + i)^n} \right),$$

where $P$ is the present value, $A$ future value, $i$ is the effective interest rate, and $n$ is the year in which it occurs. Table 2 illustrates the payment method and commutation time for each cost.

Based on the above analysis, the various cost of the life cycle of the ashore marine engine room project needs to be fully discounted to the project’s initial phase. The dynamic model formulation is

$$LCC_{D} = F_{DC} + F_{AC} + F_{IC} (1 + i)^{-n_{IC}} + (A_{OPC} + A_{MPC} + A_{EC}) \left( \frac{(1 + i)^n - 1}{i(1 + i)^n} \right) + F_{OBC} (1 + i)^{-n_{OBC}},$$

where $F_{DC}$ is the present value of design cost; $F_{AC}$ is the present value of acquisition cost; $F_{IC}$ is the present value of installation cost; $A_{OPC}$ is the present value of operating cost; $A_{MPC}$ is the present value of maintenance cost; $A_{EC}$ is the present value of environmental cost; $F_{OBC}$ is the present value of obsolete cost; $n_{IC}$ is the number of years of installation; $n$ is the number of years of operation to the age of obsolescence; $n_{OBC}$ is the number of years of design to the era of obsolescence and is the effective interest rate.
3. Life Cycle Cost Sensitivity Analysis

To analyze and predict the impact of uncertainties on the life cycle cost of an ashore marine engine room as the uncertainty changes, the sensitivity analysis will help identify how the ashore marine engine room can withstand adverse changes in the uncertainties and investigate these sensitivities in further depth [22].

3.1. Establishing Analysis Parameters. The ashore marine engine life cycle cost sensitivity analysis is based on deterministic economic analysis. Based on the concept of ashore marine engine room life cycle cost, the sensitivity analysis can be carried out around the most critical indicator of the present value of cost.

3.2. Selecting the Uncertainty Factors for Analysis. Many factors impact the economic evaluation of ashore marine engine room projects. The main influencing factors that may cause the investment effect of the project in the different phases of the ashore marine engine room project are design, acquisition, installation, operation, maintenance, obsolescence, and environmental protection cost.

3.3. Quantitative Analysis of the Amount of Uncertainty Change as a Function of the Value of the Analysis Index. According to the engineering practice, a reasonable fluctuation range of uncertainty factors is assumed, and the variation of uncertainty factors can change their values according to a particular variation range (e.g., ±5%, ±10%, ±20%). Next, the interrelationship between the change in uncertainty and the value of the analysis index is calculated. A functional relationship between the uncertainty and the analysis index is established and represented in a graph to determine sensitive factors. The sensitivity of the economic analysis indicators of the study program to change in the uncertainty factors can be expressed as a sensitivity coefficient. The formulation is [23]

$$\beta = \frac{\Delta A/A}{\Delta F/F},$$

where $\beta$ denotes the sensitivity coefficient of analysis indicator to uncertainty factor $F$; $\Delta F/F$ denotes the rate of change of analysis indicator $F$; $\Delta A/A$ denotes the rate of change of evaluation indicator when $\Delta F$ changes in uncertainty factor $F$.

4. Case Study

The life cycle cost calculation process is as follows: (1) estimate the value of the cost of each phase, the payment method, and the time period of the cost of each phase; (2) obtain the life cycle year, interest rate, and inflation rate parameters; and (3) use the formula to calculate.

The building area is 5000 sq. ft. The ashore marine engine room was calculated. The specific parameters of the two options were as follows. Table 3 shows the technical parameters of the diesel engines for the two options.

Option 1: 4400 kW medium-speed four-stroke marine diesel engine as main power propulsion unit with a 30-year life cycle, type: 9G32 (Figure 5)

Option 2: 4350 kW low-speed two-stroke marine diesel engine as main propulsion unit with a 30-year life cycle, type: WARTSILA 5RT-flex35 (Figure 6)

4.1. Cost Estimation. Due to the minimal number of units built in the ashore marine engine room, it is more difficult to collect specific data in this paper. Simplifications need to be made in some of the cost estimates. Particular explanation: the author’s department had planned the construction of an onshore marine engine room since 2011, and civil works officially started in 2013. The diesel engine acquisition was completed in 2011. The operational date was 2017, and the scrapping date will be 2043.

(1) Design cost estimation: building design cost estimate of RMB 1 million, artistic design estimate of RMB 100,000, and ship automation engine room layout design of RMB 1 million. The calculation time point is 1 January 2013.

(2) Acquisition cost estimation: Referring to the basic situation of the marine diesel engine market, the market price per kilowatt for more advanced self-developed diesel engines in China is US$210–230, and the market price per kilowatt for diesel engines manufactured under license from globally known brands is US$360. Estimates were made for both main engines at the 2011 US dollar to the RMB exchange rate of 1:6.5. Table 4 shows the price list of diesel engines.

(3) Installation cost estimation: According to the Chinese shipyard construction practice, diesel engine cost, auxiliary equipment cost, piping, electrical installation, and commissioning cost each account for 1/3 of the total construction capital. Civil works are estimated at RMB 6,000 per sq. ft. The floor area is estimated at 5,000 sq. ft. The calculation time point is 1 January 2013.

| Type        | Time     | Payment methods |
|-------------|----------|-----------------|
| Design      | Base time| One time        |
| Acquisition | Base time| One time        |
| Installation| Installation time| One time |
| Operation   | Operation time| Equal payment |
| Maintenance | Operation time| Equal payment |
| Environment | Operation time| Equal payment |
| Scrap       | Final year| One time        |

Table 2: Payment method and commutation time for each cost.
Operating cost estimation: 1. It is assumed that the main engine and auxiliary engine run continuously at full load everyday for one natural year. 2. The fuel grade is IFO380, and the international fuel price is 374 USD/ton. Table 5 shows the operating cost. This operational phase starts in 2018 after successfully accepting the construction of the ashore marine engine room.

(5) Maintenance cost estimation: ashore marine engine room needs to be staffed with one chief engineer, one first officer, one second officer, one third officer, and three mechanics. Referring to the C class first-class crew salary measurement, the monthly salary of the engine room team is RMB 106,000, which is a total of RMB 1.27 million per year. The calculation time point started in 2018.

(6) Environmental protection cost estimation: its generated waste gas is treated by a desulphurization tower to meet the emission standard, waste oil is treated centrally according to the city's hazardous chemical recycling, and its generated environmental protection cost is estimated at RMB 500,000 per year.

(7) Scrapping cost estimation: there is no ashore marine engine room scrapping case in China, lacking corresponding cost data. It occupies a low proportion of

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Table 3: Technical parameters of diesel engines.

| Category          | Option 1               | Option 2               |
|-------------------|------------------------|------------------------|
| Type              | Four stroke            | Two stroke             |
| Number of cylinders | 9                      | 5                      |
| Cylinder diameter | 32 cm                  | 35 cm                  |
| Fuel consumption  | 185 g/(kWh)            | 176 g/(kWh)            |

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Figure 5: Physical views of the 9G32 diesel engine.

Figure 6: WARTSILA 5RT-flex35 model drawing.
the full cycle cost, mainly in the dismantling and transportation, estimated at 500,000 RMB. The calculation time point is the last year.

Based on the above analysis, the cost of each of the two options is shown in Table 6.

The initial investment includes design costs, acquisition costs, and installation costs. The initial investment of Option 1 is 5183.4 million RMB, and Option 2 is 6263.7 million RMB. The table above shows that the initial investment for Option 1 is RMB 10.803 million lower than Option 2, and the operating cost for Option 1 is RMB 1.078 million higher than Option 2, with the rest of the cost being the same.

4.2. Modification of Life Cycle Cost Estimates. According to the above study, the above types of costs are generated in the design stages, construction stages, operation stages, and scrapping stages of ashore marine engine room. Time is an important influencing factor. For a more accurate calculation, the time value of money cannot be ignored. When analyzing the costs, it is necessary to convert the currency to the same time point. The base rate is 6.12%, and the inflation rate is 2.6%. Table 7.

Based on the Table 7, the life cycle cost of the options can be calculated separately.

Comparing the above two options together, Option 1 has a present value of RMB390,878,000, and Option 2 has a present value of RMB382,497,300, with Option 2 having a lower cost over its life cycle.

4.3. Sensitivity Analysis. The ashore marine engine room project was subjected to a sensitivity analysis in which maintenance, environmental protection, and scrapping costs were neglected as they did not affect the project to a significant degree. Assuming that the percentage change in acquisition cost is a, the percentage change in outfitting cost is b, and the percentage change in operating cost is c. Given a, b, c, values of ±20%, the present value of the ashore marine engine room can be calculated, and the results are shown in Tables 8 and 9.

Table 8 shows that the life cycle cost in option 1 is most sensitive to operating cost, acquisition cost, and installation cost.
Table 8: Changes in the present value of Option 1 (million RMB).

| Uncertainty factor | Rate of change | Value of cost change | Present LCC value | Value of LCC change | Rate of change | Sensitivity factor |
|--------------------|----------------|----------------------|-------------------|---------------------|----------------|------------------|
| Basic              | 0.00           | 39087.88             |                   |                     |                |                  |
| Acquisition cost   | 0.20           | 5178.72              | 39951.00          | 863.12              | 0.02           | 0.11             |
| Installation cost  | −0.20          | 3452.48              | 38224.76          | −863.12             | −0.02          | 0.11             |
| Operating cost     | 0.20           | 789.36               | 39202.34          | 114.46              | 0.0040         | 0.02             |
|                    | −0.20          | 526.24               | 38973.42          | −114.46             | −0.0040        | 0.02             |
|                    | 0.20           | 2194.15              | 45282.70          | 6194.82             | 0.22           | 1.09             |
|                    | −0.20          | 1462.77              | 32893.06          | −6194.82            | −0.22          | 1.09             |

Table 9: Changes in the present value of Option 2 (million RMB).

| Uncertainty factor | Rate of change | Value of cost change | Present LCC value | Value of LCC change | Rate of change | Sensitivity factor |
|--------------------|----------------|----------------------|-------------------|---------------------|----------------|------------------|
| Basic              | 0.00           | 38294.73             |                   |                     |                |                  |
| Acquisition cost   | 0.20           | 6042.96              | 39301.89          | 1007.16             | 0.04           | 0.18             |
| Installation cost  | −0.20          | 4028.64              | 37287.57          | −1007.16            | −0.04          | 0.18             |
| Operating cost     | 0.20           | 1221.48              | 38471.84          | 177.12              | 0.01           | 0.03             |
|                    | −0.20          | 814.32               | 38117.61          | −177.12             | −0.01          | 0.03             |
|                    | 0.20           | 2064.76              | 44124.22          | 5829.49             | 0.21           | 1.04             |
|                    | −0.20          | 1376.50              | 32465.23          | −5829.50            | −0.21          | 1.04             |

Table 9 shows that life cycle costs are most sensitive to the operating cost in Scenario 2, followed by acquisition cost and installation cost.

5. Conclusions

The purpose of building an ashore marine engine room in a maritime higher education institution is to use the automated cabin for teaching and research purposes, which is characterized by the fact that the benefits are the same or cannot be measured in monetary terms regardless of the option chosen, in which case it is necessary to compare the different factors of the two options, that is, the magnitude of the cost of the option, with the minor cost being the optimal one.

(1) The initial investment of Option 1 is lower than that of Option 2 by RMB10,803,000, the operating cost of Option 1 is higher than that of Option 2 by RMB18,266,400, and the rest of the cost is the same

(2) Through the above calculation results, the present value of Option 1 is greater than the present value of Option 2, indicating that the cost of Option 1 is higher than that of Option 2 during the whole life cycle, and Option 2 is the optimal solution.

Therefore, from an economic point of view, choosing a two-stroke EFI diesel engine system for the ashore marine engine room is preferable to a four-stroke diesel engine system. A sensitivity analysis also shows that, regardless of the option chosen, the operating cost has the most significant impact on the whole life cycle cost of the project, followed by the acquisition cost and, to a lesser extent, the installation cost.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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