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**Life Cycle Costing in the maritime sector: the case of the extraordinary maintenance of a Roll-on/Roll-off ferry**

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**Abstract**. Among the different activities involved in maritime transport, maintenance covers an important role in the life cycle of a ship, in terms of security and quality, as well as of economic relevance. Thus, the evaluation of maintenance costs is fundamental for companies that want to optimize economic sustainability needs in addition to quality and security requirements. The Life Cycle Costing (LCC) represents a valid method to assess the costs involved along the whole life cycle of a product, process, or service. In this context, this study aims to assess the potential economic impacts connected to the extraordinary maintenance activities of a Roll-on/Roll-off ferry by also including the costs associated with the environmental externalities, thus applying the Environmental LCC method. The functional unit (FU) is referred to “the extraordinary maintenance of the investigated Ro-Ro ferry implemented for 47 days”, while system boundaries are defined following a “cradle-to-gate” approach. The main findings highlight that the LCC of the investigated ship maintenance accounts for €506,324.20 per FU. In addition, a negligible contribution of the environmental externalities in terms of economic impacts is pointed out. The study also underscores a trade-off between environmental and economic performance concerning the steel used in the maintenance activities.

**Keywords.** ferry, cargo ship, Life Cycle Costing (LCC), economic impact, maintenance

# Introduction

Among the different sectors in which the transportation of goods and passengers is involved, maritime transport is considered one of the most important of the European economy. Indeed, Europe accounts for the largest maritime fleet worldwide (with over 40% of the world’s ship fleet) moving around the European ports 1.8 billion tons of goods (in terms of short shipping) and about 420 million passengers in 2019 (European Commission, 2021; Fratila et al., 2021). Furthermore, among the seven identified blue economy sectors, maritime transport and the related services contributed 40% to the added value of the blue economy. In this regard, the gross value added of freight and passenger transport amounted to €11.8 billion and €7.6 billion in Europe, in 2018, respectively (European Commission, 2021). According to the data provided by the European Community Shipowners’ Associations (ECSA, 2020), the main economic impacts related to the maritime sector, and in particular to ship transport, are due to the indirect costs in which the shipping industries are involved among the supply chain phases, such as for example costs for goods and services purchased for shipbuilding or maintenance. This underscores the need for assessing such economic impacts by following a life cycle thinking (LCT) approach, and thus applying the Life Cycle Costing (LCC) method which allows assessing the economic performance of a product, process, or service throughout its whole life cycle. In addition, the LCC method also permits accounting for the costs associated with the so-called environmental externalities (i.e., the indirect costs to be internalized that are caused by the environmental impacts) (Hunkeler et al. 2008).

Among the different phases of the life cycle of a ship, extraordinary and ordinary maintenance is a very important activity because it ensures travel security, efficiency, and cost reduction. Nevertheless, the processes involved also require high expenditures in terms of materials purchased, labor, and services (e.g., dry-dock). As pointed out by Mondello et al. (2021), among the international scientific literature, different approaches have been used to evaluate the costs connected to the maritime transport (e.g., Capital Expenditures, Cost-Benefits analysis, etc.), but few studies adopted the LCC, and none of these focused on the maintenance activities. Besides, although the term LCC is mentioned in various analyses, the proposed methods are not commonly related to the LCT approach (Mondello et al., 2021). In this context, this study aims to evaluate the economic impacts related to the extraordinary maintenance activities of a Roll-on/Roll-of (Ro-Ro) ferry using the LCC method and including the costs associated with the environmental externalities.

# Material and methods

This section reports a brief description of the Ro-Ro ferry under investigation and the LCC method used for assessing the economic impacts.

## The Ro-Ro ferry

The naval unit investigated in this study is a Ro-Ro ferry used for the transportation of wheeled vehicles through short shipping routes. The characteristic of Ro-Ro cargo ships is that loading and unloading procedures are made without using cranes, indeed vehicles move to the ship by rolling. The maintenance activities carried out on the investigated ferry are ordinary and extraordinary. The ordinary procedures are made every month and commonly include a general inspection of engines, outfitting and ship’s compartments. The extraordinary maintenance is carried out through dry-dock, thus suspending the transport activities. It implies the overall inspection and maintenance of the ferry, including refurbishment/restoration or substitution of components, as well as carpentry, washing, and painting processes in the hull and superstructure.

## Life Cycle Costing

The LCC is a method that allows the assessment of all costs, in monetary terms, related to a product, process, or service throughout its whole life cycle, from the production processes to the end-of-life (Rebitzer and Seuring, 2003). According to Hunkeler et al. (2008), three different types of LCC can be implemented, i.e., Conventional LCC, Environmental LCC (ELCC), and Societal LCC. In this study an ELCC is performed. ELCC adds to the life cycle costs (accounted in a conventional LCC) the externalities that are expected to be internalized in the decision relevant future. Thus, it allows the internalization of the costs, along the life cycle, connected to the “not-monetized” Life Cycle Assessment (LCA) results, related to the environmental impacts caused by the product, process, or service. This means that when the ELCC is implemented also a LCA shall be applied (Swarr et al., 2011). The ELCC has been here used to assess:

* the costs connected to the extraordinary maintenance activities carried out on the investigated Ro-Ro ferry, including i) dry-dock, ii) engines and propellers, iii) outfitting, iv) valves and pumps, v) pipes, and vi) structures (i.e., hull and superstructure);
* the costs of the environmental externalities related to the utilities (electricity and water) used during the extraordinary maintenance, as well as the steel parts which were substituted during the maintenance activities (carpentry processes and pipes replacement). The focus on steel is due to the fact that it represents the primary material of a cargo ship, and it is one of the principal contributors to the environmental impacts related to the life cycle of a ship (Tuan and Wei, 2019).

The functional unit (FU) identified for carrying out the analysis is related to “the extraordinary maintenance of the investigated Ro-Ro ferry implemented for 47 days”. In addition, system boundaries (SBs) are defined following a “cradle-to-gate” approach (figure 1), from the dry-dock to the time in which the Ro-Ro ferry is ready to be launched. SBs also include the purchased materials and energy sources as well as the costs related to labor. As previously stated, the costs connected to the environmental externalities are accounted only for utilities and steel.



Fig. 1. System boundaries and cut-off.

In order to build the life cycle inventory, data on costs were gathered through questionaries and direct interviews submitted to a company operating in maritime transport. The impact assessment for the LCC is based on the evaluation of all the costs related to the Ro-Ro ferry’s extraordinary maintenance accordingly to the identified FU and SBs:

 $LCC= \sum\_{i=1}^{maintence activities}(maintenance costs )$ (1)

For externalities calculation, the Environmental prices method (De Bruyn et al., 2018) is applied. This method allows the assessment of the potential environmental impacts using the characterization factors based on ReCiPe 2008 Midpoint (Goedkoop et al., 2009) and IPCC (2013); besides, it accounts for the costs related to the environmental externalities expressed as average European prices in Euros per kilogram of pollutant.

# Results and discussion

The economic impacts of the extraordinary maintenance activities of the Ro-Ro ferry under investigation are reported in figure 2.



Fig. 2. Contribution analysis of the extraordinary maintenance of the Ro-Ro ferry (LCC results).

The total costs associated with the processes involved in the maintenance are equal to €506,324.20 per FU. The main contribution to the economic impacts is due to the ship’s superstructure maintenance (26.8%), followed by engines and propellers maintenance (20.4%) and by dry-dock activities (16%). On the contrary, the lower costs are related to the use of auxiliary materials and utilities contributing respectively for 1.2% and 0.3% to the impacts. Regarding superstructure maintenance, the painting process is responsible for the highest impact. Indeed, the surface painted during the investigated maintenance activities is about 16,000 m2 per FU, including single, double, or triple paint layers for walls, ceilings, railing, stairs, etc. For engines and propellers, the main contribution is associated to the check of two propellers and related screws, which includes the disassembly and reassembly of the parts as well as the substitution of specific components (e.g., springs, bearings, etc.). In addition, the results also highlight the high costs caused by the dry-docking, related to the use of the crane, which accounts for about €40,500 per FU. An in-depth analysis of the ship’s structures maintenance (figure 2) highlights that the painting processes cause the highest costs in both hull and superstructure, while the washing activities, for which designated machinery (e.g., high-pressure cleaner and robot) are adopted, result in economic impacts ranging from 18.6% to 33.8%. Besides, the steel used in pipes replacement and carpentry is responsible for 15.5% of the impacts among the whole maintenance activities, resulting in €78,490.87 per FU. The results obtained through the application of the ELCC method are reported in figure 3.



Fig. 3. ELCC results and related contribution analysis to the environmental externalities.

Concerning the environmental performance of the investigated extraordinary maintenance activities, it emerges that the steel provides the main contribution to all the analyzed impact categories, except for agricultural land occupation and water depletion for which the highest impacts are respectively due to electricity and water. The costs related to the environmental externalities account for €2,304.08 per FU, causing a negligible contribution (0.5%) to the total ELCC. In particular, as shown in figure 3, the highest contribution to the environmental externalities is due to the steel used in pipes replacement (€1,141.17 per FU).

# Conclusions

This study aims to evaluate the economic impacts related to the extraordinary maintenance of a Ro-Ro ferry, accounting for all the costs of the activities, materials, and utilities as well as for the expenses related to the environmental externalities, through the application of the ELLC method. The highest contribution to the economic impacts is caused by the painting process of the superstructure, followed by the propellers’ maintenance and the use of cranes during dry-docking. The main findings underscore that steel causes the highest impacts among all the investigated impact categories and that environmental externalities have a negligible contribution to the total ELCC. Results also point out a trade-off between the environmental and economic performance of the investigated extraordinary maintenance activities. Specifically, the trade-off is referred to the steel used: despite its low contribution in terms of costs, it is responsible for the highest environmental impacts.

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