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Life Cycle Cost Analysis of Complex Systems: an application to shipbuilding

A. Frias[a,b,*], P.B. Água[a], B.F.M. Lopes[a], P.S. Melo[a]

[a] CINAV, Escola Naval, Instituto Universitário Militar, Almada, Portugal;
[b] Advance/CSG, ISEG-Universidade de Lisboa, Lisboa, Portugal

ABSTRACT

The use of integrated logistic support methods and the calculation of life cycle costs, provide a comprehensive view of the total value of a system over time. A project for the construction of two lifeboats is studied and a life cycle analysis is proposed, identifying and highlighting the system cost structure of each phase in time, from design to disposal. The results help evaluate the project sustainability and carry out its management, supporting decision-making in different phases, planning and controlling the operation and maintenance of the system, and obtaining the necessary resources.

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*Corresponding author:
Armindo Frias
armindo.frias@gmail.com

1. Introduction

Any organization that intends to develop a high-scale or complex project, that last over time, should consider the impact of such long term on the project development and implementation. The project lifetime activities and related costs should be assessed [1,2]. A project can be defined as a set of interconnected tasks that must be accomplished within a given period, budget, and other constraints while achieving a given objective. The development of a project requires assertive planning to obtain a final product capable of meeting the needs that justify its existence. This planning should establish its economic viability and provide reliable information about the expected costs for its entire life cycle [3,4].

In order to support decision-making, the need arises to resort to a method that value each feasible option. Integrated Logistic Support (ILS) body of knowledge is used as a methodology with appropriate tools for such purpose. The use of these tools adds value to project design, selection, and proper monitoring, avoiding waste of time and financial resources. The calculation of the Life Cycle Cost (LCC) makes it possible to predict the relevant costs that will incur for the asset, equipment, or system life cycle.

To determine the appropriate Logistic Support (LS) for each phase of the project and related costs, the LCC is the chosen approach. This tool helps in planning the activities to be carried out throughout the project's different phases and related expenses. When done in anticipation of the project, as a plan-

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ning tool, it constitutes powerful support for decision-making.

Organizations like the Navy or maritime companies regularly need to acquire new ships to carry out their missions. The design, acquisition, operation, and disposal of ships is in itself a project with a normal length of 25 to 40 years and involves the use of relevant human, financial and material resources. The Portuguese National Maritime Authority, as part of the Portuguese Navy, is a public entity responsible for the safety of human lives at sea, performing surveillance, rescue, and assistance to castaways and swimmers. To perform such missions, it needs specific vessels, adapted for coastal operations, sometimes facing harsh sea conditions. To increase the resources available, the need to acquire two lifeguards' vessels identical to the existing "Vigilante" class has been identified.

The *Arsenal do Alfeite*, S.A. is a State-owned Shipyard, part of the National Defense Industry, with extensive experience in shipbuilding and maintenance of naval assets. Recently, the Portuguese Navy hired *Arsenal do Alfeite* to build two lifeboats identical to a previously designed one. The project was named "Vigilante II" [5].

This study identifies the tasks and resources needed to carry out the logistical support of a system like a ship, through the application of the LCC, defining the main tasks and cost structure associated with each phase of the project life cycle. The used methodology relied on direct contact with people who were part of the project, in order to obtain data related to each phase's cost structure and associated expenses, allowing the calculation of the LCC.

The obtained results support decision-making and help to design, produce, operate and control the different activities of the system under study. With the necessary adaptations, this study is applicable to similar cases, whether in the shipbuilding industry or another.

2. Background

2.1 Theoretical concepts

ILS refers to the intentional integration, at the beginning of a program or project, of logistical support elements for the life cycle management of systems and equipment, where all necessary elements for the establishment of effective logistical support should be planned, purchased, tested, and delivered economically and on time [6]. In the same sense, the Council of Supply Chain Management Professionals (CSCMP) [7] considers that ILS refers to the process of managing the entire life cycle of a product, encompassing its design, development, manufacturing, market introduction, transaction, or use and disposal. The introduction of environmental and social concerns is a recurrent topic within the supply chain literature [8]. Jones [3] presents a more comprehensive and generic definition where ILS is a body of knowledge and a unified management method for all the activities necessary to design a workable system and the associated support to achieve a predetermined set of measurable objectives within an acceptable cost of ownership.

ILS is a field of knowledge and a management support method that, in a comprehensive and integrated way, seeks to harmonize and create coherence between the various components involved in the logistical activities to support systems, equipment, or products operation, throughout their lifetime. Being conducted in a planned manner, at the beginning of the project, it aims to optimize the operational availability of the system and the efficiency in the use of the necessary resources throughout the different stages of its useful life.

The activities carried out under the ILS approach may be gathered in different phases. Although there is no unanimity, in most cases such classification ends up being mixed with the acquisition process and with the system life cycle phases itself, largely because it is an essential part of the ILS configuration. The ILS activities begin even before the systems acquisition and only end with the completion of their useful life. Jones [3] identifies the phases of the acquisition cycle as pre-acquisition, acquisition, and support.

The pre-acquisition phase defines the existing need. It can be seen as a minor task but, when considered in an ILS context, it is of crucial relevance for the development of the project. Defining the main function or purpose of the system or equipment to be implemented isn't enough; it is necessary to answer a whole set of questions that may have considerable impact in the following phases. Some of the questions at this stage are: "How will the system be used?", "What are the intended operations minimum performance requirements ?", "How will performance be measured?", "How will the failures of the system be measured?", "What are the limitations to the level of support?" among others, that together will properly constrain their production and support [3].

The acquisition phase begins after a suitably configured and structured project is set up, which involves the development and design of the product or system, for the purpose of materializing an idea, that is, to transform the concepts into specific items or goods [1]. Some of the main concerns at this stage are related to reliability, serviceability, and testability, among other characteristics of the product or equipment. Even at this stage, there is a need to develop and determine the sustainability characteristics to which the product must comply. These requirements are translated into project objectives, goals, and constraints, for which it is necessary to determine how should they be achieved or avoided [3].

Adequate eco-design, directly or indirectly, minimizes environmental negative impacts over the systems life cycle - through the selection of recyclable materials, energy-efficient components, low level of pollutant emissions, reduced need for maintenance or re-use after their end-of-life [9,10]. A correct life cycle planning of maintenance activities allows cost savings and systems increased availability [11,12].

Once the system has been designed and built, it gets into the operation and support phases. During these phases, the system performs the functions for which it was developed, with the aim of meeting the needs that triggered its construction [4]. The support phase takes place throughout the equipment's lifetime, until its disposal. This phase requires fewer decisions, however, at the financial level, this may be the most expensive phase since it includes all the costs of operation and maintenance [1,3]. At this point in the system life cycle, planned or corrective maintenance plays a crucial role in sustaining the system. To perform this plan, several aspects should be identified, such as the maintenance periods, who is competent to carry them out, what materials should be used, or what are the key characteristics of the system in terms of maintenance [13]. The definition of the planned or preventive maintenance periods, where the system must stop operating, so that it can be observed, inspected, tested, or repaired if needed, should be planned, based on usability forecasts, reliability, and durability specifications [2].

ILS considers the need to adapt the level of logistical support to economic factors. Jones [3] identifies three possible calculation methods to determine the costs to be incurred for a given project: (1) Life Cycle Cost (LCC) - in this approach several alternatives are compared, choosing the one with the best cost-efficiency ratio. Being this model based on expectations and estimates, its associated information may not be completely reliable. It is, however, an essential tool during the design phase as it provides information and data relevant for decision-making; (2) Through Life Cost – essentially a financial approach. This is a budgeting process that estimates the costs of an option, covering the estimated total lifetime of the equipment and sharing the costs by category according to different accounting periods. This process is usually used after the project definition stage is finished. This model requires detailed information about the equipment in question, essentially to optimize resources and not to influence the arranging of the project; (3) Whole Life Cost - estimated total resources needed to acquire, equip, operate and sustain the selected option during its estimated lifetime. This process encompasses all costs throughout the system life and adds costs related to infrastructure, training of personnel, management, and support throughout the product lifetime. It is aimed at a higher level of management as it covers all costs related to the management structure, administration, and support of the functioning system.

The classification and distinction of methods for cost calculation associated with a project as proposed by Jones [3] aren't consensual. Newnes et al. [14] consider that all terms mentioned above and others, such as "total cost" or "total cost of capital", are merely different expressions for the same concept, the LCC. The difference between the various terms is related to how they can be used, and which factors shall be considered.

LCC is a strategic management tool to support decision-making, even in the early stages of a project, that takes into account economic and technical aspects to occur over the whole lifetime [15]. The costs to be considered include the expenses to be incurred for the acquisition, operation, maintenance, modification, and/or disposal in an integrated way since the evidence suggests that the optimization of the system as a whole has advantages over the optimization of its constituent parts [16]. The objective of analyzing these costs is to choose the best cost-efficiency ratio from a number of alternatives and find the lowest cost for the equipment's entire lifetime, that is, the most advantageous total cost considering the full life cycle. As a rule, operating, maintenance, and disposal costs exceed the initial acquisition costs by a considerable margin [1].

A system's life cycle refers to the period of time that begins with the actual system design, goes to acquisition or construction, and ends with its withdrawal from use or disposal. The definition of the life cycle phases is not uniform. According to CSCMP [7], it is possible to identify five different phases in a product life cycle: product development, introduction, growth, maturity, and decline. The US DoE [4] states that carrying out a facility or system project requires a set of critical decisions to overlap the system life cycle milestones, which are: establish mission needs; identify alternatives and cost range; define performance baseline; construction; start of operations or project completion; facility operation, maintenance & upgrades; facility deactivation, decommissioning & demolition. Newnes et al. [14] report that the life cycle for defense products is divided into six phases: concept, development and analysis, demonstration, manufacture, in-service, and disposal, referred to as CADMID. However, in order to respond to needs that cannot be met by the market and where customized developments are needed, the system life cycle can be more complex, including up to six phases: concept, assessment, test and, select, design and manufacture, operation, and disposal. Blanchard [17] considers that the systems life cycle involves the initial identification of the need, the design and development, the production and/or construction, the operation and its sustaining support and, the retirement and material recycling and/or disposal.

Assessing the mentioned approaches, they exhibit some similarities, as can be seen in Table 1. The authors propose a classification comprising three phases, aiming to standardize the different perspectives. This aggregation is in line with the procurement cycle offered by Jones [3] and has a direct relation with the development of ILS. The proposal is shown in Table 1.

Life cycle costs can be divided into acquisition and support. Hence, the costs taken during the design phase as well as those taken with the construction are reflected in the acquisition value [1]. The LCC calculations represent the total costs that can be expected to occur along the different phases of a system's useful life, which makes it possible to correctly consider some long-term decisions. All calculated values should be updated to the present moment in time, in the form of Net Present Value (NPV) [18].

2.2 The “Vigilante” lifeboats

The L150-SV “Vigilante” class lifeboats are intended to perform rescue operations up to 75 nautical miles around their Lifeguard Station. These lifeboats are built using fiberglass and composite materials, with a length of 15 meters, and are prepared to operate in stormy sea conditions and in surf zones. See Figure 1. Its normal crew is three to four members [19].

Figure 1. L150-SV “Vigilante” class lifeboats [19]

Table 1. System life cycle phases

<table>
<tr><th>Jones [3]</th><th>Blanchard [15]</th><th>Newnes et al [14]</th><th>CSCMP [7]</th><th>US DoE [4]</th><th>Authors</th></tr>
<tr><td>Concept</td><td>Initial identification of a need</td><td>Concept</td><td rowspan="4">Product development</td><td>Establish mission need</td><td rowspan="4">Design and project</td></tr>
<tr><td>Assessment</td><td rowspan="3">System design and development</td><td>Assessment</td><td>Identify alternatives and cost range</td></tr>
<tr><td>Test & select</td><td rowspan="2">Demonstration</td><td rowspan="2">Define performance baseline</td></tr>
<tr><td rowspan="2">Design & manufacture</td></tr>
<tr><td>Production and/or construction</td><td>Manufacture</td><td rowspan="2">Introduction</td><td>Construction</td><td>Acquisition or manufacture</td></tr>
<tr><td rowspan="4">Operation</td><td rowspan="4">System operation and sustaining support</td><td rowspan="4">In-Service</td><td rowspan="2">Start of operations or project completion</td><td rowspan="5">Support and disposal</td></tr>
<tr><td>Growth</td></tr>
<tr><td>Maturity</td><td rowspan="2">Facility operation, maintenance & upgrades</td></tr>
<tr><td rowspan="2">Decline</td></tr>
<tr><td>Disposal</td><td>Retirement and material recycling and/or disposal</td><td>Disposal</td><td>Facility deactivation, decommissioning & demolition</td></tr>
</table>

This lifeboat's expected lifetime is 25 years. Its average annual availability will be 330 days. The standstill periods shall not exceed two months per operational cycle, approximately every two years. The estimated operational employment rate is 500 hours per year.

One of the specifications to observe in the design of ships and similar systems is their maintenance simplicity, the existence of reliable equipment, and spare parts availability. In this particular case, the maintenance must follow a Planned Maintenance Program (PMP), which gives primacy to replacement maintenance rather than repair [19]. This option has implications for the definition of the initial spare parts batches to be accommodated onboard or stored onshore, as well as their replacement over the lifeboat's useful life.

3. Life cycle costs

For the calculation of the costs associated with the "Vigilante II" project and considering the ILS to be carried out throughout the whole life cycle, the selected approach was the LCC. Whereas this is an ongoing project, having started the construction stage. According to Jones [3] the LCC would not be the option to follow. The opinion advocated by Newnes et al. [14] and presented in point 2.1. is followed.

The logistic support over the systems life cycle is related to financial factors. Although not essential, the budget availability plan is critical to define the logistical support to fulfilled during the life of the project. Ultimately, the support costs stand out due to their relevance and timespan. The level of initial investment and its typology affects the costs at later phases.

The greater the initial investment in spare parts or training, the lower the future investment for these items. One cannot, however, consider that initial investment will completely eliminate future needs, as the support period is long enough and there will be factors that cannot be accurately predicted upfront. Each of these components evolves differently and represents costs along the life support of the lifeboat. Such costs, with the exception of the ones shown in the results analysis section, relate to the time period in which they occur, not in the form of NPV.

3.1 Design and project costs

The "Vigilante II" project stems directly from a previous project for the construction of the existing "Vigilante" lifeguard vessel. The overall costs of systems designing and development and construction project have been taken and accounted for in the initial project. Residual costs associated with this phase are part of the acquisition costs. Therefore, the cost of this phase is considered to be zero.

3.2 Acquisition costs

The acquisition contracted price for the production of both lifeboats was 3M€. This value includes a set of components that go beyond the cost of the lifeboats, some of which are relevant to other life cycle phases. Based on information collected from the manufacturer, the acquisition costs include: (1) the lifeboats, including the entire physical structure of the vessel, equipment, and incorporated systems ; (2) technical documentation; (3) configuration management, including software, equipment and systems that can be accommodated onboard; (4) on-board spare parts batch; (5) onshore spare parts batch; (6) operation and maintenance training. Table 2 shows the corresponding costs.

Throughout its life cycle, the project considers a set of events that shall occur, with direct impact on the acquisition and production costs. Such future events identification is based on previous study of one of the authors [5], the Navy's technical specification for the construction of the vessels [20], historical data from the operation of the previously built "Vigilante" life-

Table 2. LCC: Acquisition and production costs [5]

Cost	%	1 lifeboat	2 lifeboats
Purchase contract value	100%	1.500.000€	3.000.000€
Lifeboat vessels	90%	1.350.000€	2.700.000€
Technical documentation	1%	15.000€	30.000€
Configuration management	1%	15.000€	30.000€
On-board spares parts (COSAL)	2,5%	37.500€	75.000€
Onshore spares parts (COSMAL)	3,5%	52.500€	105.000€
Training	2%	30.000€	60.000€

boat and other similar lifeguard vessels, together with Portuguese Navy's implemented rules. The onboard and onshore spare parts and consumables batches will be used during the maintenance activities to occur. So, in the next phase, they will be considered for the calculation of the corresponding stock replenishment. The configurations of the main onboard systems shall be upgraded in the mid-life maintenance actions and staff training shall be regularly increased. No reinvestments are foreseen for the components of the vessel structure itself or for technical documentation.

3.3 Support and disposal costs

The lifeboats support costs include their operation, according to operational commitment forecasts, maintenance costs related to the planned Maintenance program, and corrective maintenance actions [20].

Operating costs - The expected main costs associated with this ship's operation, is related to personnel, fuel, and general consumables. The personnel's key cost components are crew salaries, employers' social expenses, and food allowance on mission days. The cost calculation factors for personnel include three crew members, 330 mission days per year, and 14 months of salaries, together with the employer's contributions to the social protection system. Salaries were obtained by calculating the average salary of persons who may be employed on board this type of vessel. By law, the contribution to the social protection system is 23,75% of the salary. In addition to the food allowance included in the salary (lunch), when at sea, sailors are entitled to an additional meal (on the operation start date (4,77€)).

The lifeboat operational usage has a direct impact on fuel consumption, whose cost calculation is based on the expected operational employment (average 500 hours/year), average consumption per hour, and the average price of the fuel diesel used by the vessels (0,50€/liter).

General consumables concern all materials of immediate consumption and with a minor financial significance, which is important for a smooth operation. Its value is taken as 10% of the onshore spare parts batch value.

Maintenance support costs - Investment in the training of operators and maintenance personnel is planned for every five years, except for the last period, due to the forthcoming boat's end of life. Such costs correspond to 10% of the value initially defined for training.

Maintenance actions, whether planned or corrective, should be foreseen and funds allocated. One of the critical enablers of maintenance activity is the availability of spare parts and consumables. To support the necessary replenishment of on-board and onshore spares and consumable stocks, a reinvestment on on board spares are foreseen every two years. The expenses should correspond to 20% of the value assigned to the on-board spare parts batch for the initial batch. Moreover, a reinvestment on onshore spares batch will take place every two years, following the planned maintenance, except for the last period, since it is considered unnecessary to reinforce it at a time when the system's end of life is approaching. The reinforcements made should be 10% of the initially attributed value for the onshore spare parts batch.

For configuration management, there may be a general update to the vessel design, which should take place roughly midway through its life cycle, corresponding to a cost of about 20% of the value initially foreseen for this item. Considering the project technical specifications [20], the lifeboats must be submitted to planned maintenance actions every two years, lasting about two months. The estimated costs for each of these interventions correspond to 5% of the vessel acquisition cost.

During their lifetime, the vessels will inevitably be subject to small corrective maintenance actions, which do not require significant resource commitments and for which an accurate forecast is not possible. These corrective maintenance actions must be taken into account in the calculation of the LCC. To estimate them, a cost of 1% of the vessel cost has been defined. Although it is known that it can vary over time, following the "Bathtub curve" behavior, this cost should be distributed evenly over two years, between planned maintenance.

Besides the planned and corrective maintenance actions, Repair of Repairable (RoR) spare parts shall be considered. Its calculation is based on the estimate that 2,5% of the value of the onshore spare parts batch will be used during the years when planned maintenance is expected, except in the last year. In the years preceding those of planned maintenance, a cost of 1% of the value of the same batch is considered.

Disposal costs - For the end of the life, the project foresees the lifeboat sale in full or for parts, so it is reasonable to foresee the existence of costs with disassembly and environmental processing. A return from the sale of the vessels or their equipment is also expected, although lower than the costs.

4. Results and Discussion

To compute de LCC of this project, the three phases system proposed by the authors in Table 1 was adopted. The initial amounts spent on supplies and training, although they represent an initial expense paid together for the vessels acquisition, they are intended to provide subsequent logistical support. Thus, these are considered as belonging to the support phase.

The "Vigilante II" project's total cost, considering the two vessels and the estimated 25 years old lifetime, is 8.636.077€ (Table 3). The design phase assumes zero costs, since most of them have already been supported in the acquisition of previous lifeboats, and, existing residual values have been included as part of the acquisition costs. At the acquisition or manufacture phase, the vessel purchasing cost encompasses the full range of costs. The support and disposal costs include the forecasted relevant expenses to bear the operation, maintenance, and disposal.

The results analysis shows that the acquisition and manufacturing phase represent about 31% and the support and disposal about 69% of the whole project. If compared with the theoretical values presented by Jones [3, p.11.7], with 14% for the first two phases (investment, research, and development) and 86% for the phases of operation, support, and disposal, the results suggest that the initial phases have a higher weight than would be expected. This may be explained by the fact that the figures presented by the literature are not customized to the shipbuilding industry or, because this is a relatively small shipbuilding project, that does not achieve significant economies of scale or, it is due to the cost structure of this particular manufacturer. To maintain competitiveness, it is vital for companies to follow emerging trends in production. Another reason may be the underbudgeting of the support phase, due to the non identification of all costs involved.

Regarding the support and disposal phase costs, the operation represents around 68%, the maintenance about 31%, and the disposal near 0,4%. That is, operating the vessels is significantly more expensive than its maintenance and disposal, as would be expected (e.g. [18]). Operations' main costs are related to personnel (nearly 52%) and fuel (nearly 48%). On the other hand, for the maintenance support, the main expected costs are those related to the maintenance actions (planned and corrective), 73%. The acquisition and sustainability of spare parts (onboard and onshore) and their RoR costs, a total 20, have a relevant impact on the maintenance support costs.

The disposal phase costs are about 0,4% of the total cost of support and disposal phase, and less than 0,27% of the total project cost. Jones [3, p.11.7] sug-

Table 3. Total life cycle costs

Phase and main cost typologies	2 lifeboats	2 lifeboats*	1 lifeboat*	%
3.1. Design and project	**0 €**	**0€**	**0€**	**0%**
3.2. Acquisition and manufacture	**2.700.000€**	**2.686.634€**	**1.343.317€**	**31%**
3.3. Support and disposal	**6.752.743€**	**5.949.444€**	**2.974.722€**	**69%**
3.3.1. Operation	**4.641.568€**	**4.069.881€**	**2.034.941€**	**68%**
Personnel	2.394.997€	2.099.371€	1.049.686€	52%
Fuel	2.209.821€	1.937.053€	968.526€	48%
General consumables	36.750€	33.458€	16.729€	1%
3.3.2. Maintenance support	**2.081.175€**	**1.856.285€**	**928.142€**	**31%**
Training	78.000€	75.617€	37.808€	4%
Technical documentation	30.000€	29.851€	14.926€	2%
Configuration management	36.000€	35.150€	17.575€	2%
On-board spare spares batch (COSAL)	195.000€	179.270€	89.635€	10%
Onshore spare spares batch (COSMAL)	178.500€	169.501€	84.750€	9%
Repair of repairable (ROR)	24.675€	21.798€	10.899€	1%
Planned maintenance actions	1.080.000€	941.771€	470.885€	51%
Corrective maintenance actions	459.000€	403.327€	201.664€	22%
3.3.3. Disposal	**30.000€**	**23.277€**	**11.639€**	**0%**
Total	**---**	**8.636.077€**	**4.318.039€**	**100%**

* Figures in NPV, at a rate of 1% a year
Source: adapted from Lopes [5], Arsenal do Alfeite [19] and Marinha [20]

gests they could be 1% of the total project cost on average, however, in the present case, the obtained value is significantly lower. This difference may be explained by the vessels' sales forecasted return or their components, at the end of their useful life, together with the choice of materials, equipment, and assembly techniques chosen during the design phase. Figure 2 displays these previous figures in a graphic way.

For the project supporting organization to assess it, it is relevant to know its average annual costs. Considering the two vessels and the 25 years of service life, the annual average costs for the project are 345.443€. For the entity responsible for supporting operation and maintenance costs to plan its activities and budgeting, it is relevant to know the average figures. For the operation of one lifeboat, the mean annual cost will be 81.398€, and to maintain it, 37.126€, which means an average annual total cost of 118.989€.

Considering the project's financial needs, Figure 3 presents the total costs taking place each year. Year zero refers to the construction of the first vessel. The difference in values from years zero and one for the remaining years is related to the acquisition of the two vessels, one each year. From year one to year twenty-five, the variation in values is due to different maintenance actions, spare parts acquisition and repair, training, and configuration management needs. Year twenty-six is all about the disposal costs of the second lifeboat. Excluding the first two periods, the remaining years' have low-cost variability. This relative stability of costs over time is due to the existence of two vessels with lifetimes lagged by one year, and the fact that the purchase of spare parts takes place in years when there are no planned maintenance actions. Excluding the acquisition, support, and disposal costs are circa 238.000€ yearly.

For the entity responsible for planning the operational activity, it is important to know the hourly usage costs and the breakdown between fixed and variable costs. Given the expected operational employment, the average cost of support and disposal of each lifeboat is 238€/hour. In terms of operating costs, a 163€/hour is expected. Considering the costs with personnel as fixed and the costs with fuel and general consumables as a variable, giving 84€/hour of fixed costs and 78€/hour of variable costs in terms of usage.

5. Conclusion

ILS presents itself as a theoretical body of knowledge that provides a comprehensive and multidisciplinary approach. During a project's analysis phase, it provides a complete view of the whole system where, in addition to the initial development and acquisition costs, the expected costs for the entire

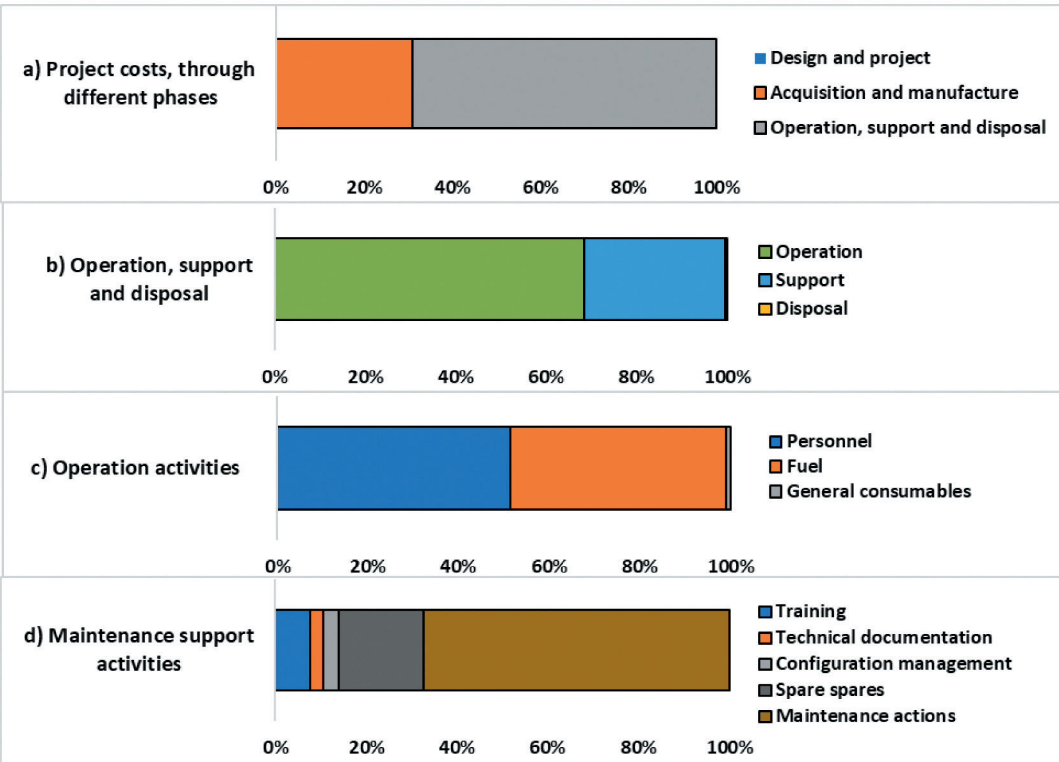

Figure 2. Project: most relevant LCC breakdown

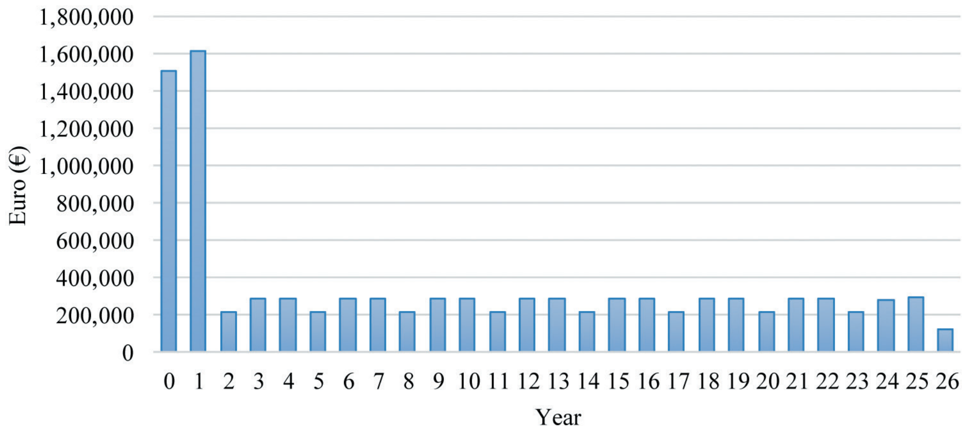

Figure 3. Project financial needs per year

life are taken into account. Its multidisciplinary approach enables interconnection with different areas, such as accounting, human resources management, or system maintenance, making cost identification as realistic as possible.

The study of the "Vigilante II" project, allowed the identification of the main logistics activities and financial resources needed to operate and support them during their 25 years estimated useful life. In addition to the operating costs, this study highlights the importance of the maintenance actions needed to maintain the lifeboat's operational availability ensuring adequate reliability. The planned maintenance actions require a two months stop every two years.

The existence of a one-year gap between the two vessels' age and the implementation of a spare parts' purchase policy, focused on the years when there are no planned maintenance actions, keeps a relative steadiness on the needs resources to support the operational activities and maintenance, easing the budgetary and financial management.

Future research could include similar studies taken for different shipbuilding projects or, expand this study with the inclusion of environmental and social factors in the analysis. The manufacturing industry, to be sustainable, shall respect the three pillars of sustainability [21]. The shipbuilding and maritime operations still have a considerable environmental footprint, therefore, the analysis of these factors may help discover sustainable solutions. *Arsenal do Alfeite* shipyard is a public company that has experienced financial distress over the years, but the fulfillment of this construction project had a relevant social and cultural impact on the local populations.

The implementation of an ILS approach to the analysis of shipbuilding projects has revealed itself as a crucial tool for planning the operational activity of naval assets and, the fulfillment of the activities that promote the sustainability of the project. An LCC analysis contributes to the systemic management of the needed resources throughout the system's lifetime, including financial ones, and supports strategic decision-making.

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