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Literature Review on Costing Strategies of Radar System Remanufacturing

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Abstract

The purpose of this literature review is to explore the current state of knowledge and understanding of the cost of designing radar systems for the maritime sector, with a focus on remanufacturing. The review aims to identify the key cost engineering techniques and tools used in the design of radar systems, as well as the best practices and challenges encountered in this area. The review also aims to identify any knowledge gaps or areas that require further research in order to improve the cost and quality of radar system remanufacturing in the maritime sector. By collating and synthesizing the existing literature, this review aims to provide a comprehensive overview of the current state of the art in radar system design costing for remanufacturing in the maritime sector, and to identify key areas for future research and development. The remanufacturing of radar systems for the maritime sector has garnered increasing interest in recent years due to the need to address the end-of-life stages of such products. However, there is limited literature available on the cost of designing radar systems for the maritime sector and how product design techniques can be used in remanufacturing processes. This study aims to review the current literature on design costing frameworks, cost trade-off techniques, and cost estimation methods used in other sectors that can be applied to maritime companies in order to improve the reliability and quality of radar systems for end-users, shipyards, naval forces, and oil and gas tankers. By conducting an exhaustive benchmarking analysis of industrial best practices, this study aims to identify how product life cycle costing solutions can be used to reduce the cost and improve the quality of future maritime products and new radar systems through custom configuration changes. Additionally, the study aims to understand the importance of cost-driven strategies for remanufacturers to remain competitive in the second lifecycle of products.

Keywords: Cost Trade-off, Design Costing, Nonrecurring Cost, and Unit Production Cost

Highlights

The key highlights of this literature review are:

➢ Identifying the product cost drivers for nonrecurring costs and unit production costs in the context of radar system remanufacturing in the maritime sector.

➢ Developing a design to cost template and identifying best costing practices to use for organizations involved in the remanufacturing of these systems.

➢ Examining the cost trade-offs between different product design routes, such as make or buy decisions, and developing parametric cost estimation models to help organizations make informed decisions about the most cost-effective design options.

Introduction

Research on the cost of product design remanufacturing can provide valuable insights into the challenges and best practices for cost estimation in the maritime sector when manufacturing or remanufacturing radar systems. Remanufacturing involves returning end-of-life products to "like new" condition with a warranty, and is a viable option for high-risk and high-value radar systems that can be improved in quality through redesign or remanufacturing. To support this process, it is important to develop parametric cost trade-off models for the costing of design templates, which can be achieved through benchmarking the current practices and tools used in radar systems. Detailed descriptions of the remanufacturing process can be found in previous research on successful remanufacturing organizations [1, 2, 3]. The goal of this literature review is to contribute to the understanding of these issues and best practices in the context of radar system remanufacturing in the maritime sector. Lifecycle costing of products has become a critical business driver for a variety of industries, including consumer electronics, aerospace, automotive, electronics manufacturing, maritime, medical, and software product design, as it can help improve the quality of remanufactured products. As a result, cost engineering studies have gained importance in both academia and industry. Remanufacturing provides a profitable business opportunity because it allows for the reuse of most raw materials and can result in energy and cost savings compared to newly manufactured products [4, 5]. The process of remanufacturing typically involves disassembly, cleaning, inspection, rework, reassembly, and testing [6,7]. These activities are important at the end-of-life for using the 8D investigation tool to identify the root cause of failure and implement design changes to reduce risk in the maritime sector for high-value products. Remanufacturing was initially implemented in the automotive industry, but has since been adopted in many other sectors [8, 9,10]. This literature review aims to contribute to the understanding of these issues and best practices in the context of radar system remanufacturing in the maritime sector. A literature review on the costing of radar system remanufacturing can provide valuable insights into the factors that affect the cost of remanufacturing these systems. There are several research references that have been published on this topic, and the following paragraphs summarize some of the key findings from these studies. One key factor that affects the cost of radar system remanufacturing is the complexity of the system being remanufactured. Systems that are more complex, with a larger number of components or subsystems, are likely to be more expensive to remanufacture. This is because they require more labour and specialized equipment to disassemble, repair, and reassemble. Another important factor is the availability of spare parts and components. If the parts and components needed for remanufacturing are readily available, the cost will be lower. However, if these parts are scarce or have to be specially ordered, the cost may be higher.

The condition of the system being remanufactured can also affect the cost. If the system is in good condition, with minimal damage or wear and tear, it will be easier and less expensive to remanufacture. On the other hand, if the system is in poor condition and requires extensive repairs or replacement of multiple components, the cost will be higher. Finally, the scale of the remanufacturing project can also impact the cost. If the project is large, with multiple systems being remanufactured at once, the cost may be lower due to economies of scale. However, if the project is small and only involves the remanufacture of a single system, the cost may be higher due to the lack of economies of scale. Overall, the cost of radar system remanufacturing is influenced by a range of factors, including the complexity of the system, the availability of spare parts and components, the condition of the system, and the scale of the project. Understanding these factors can help organizations make informed decisions about the cost and feasibility of remanufacturing their radar systems.

Purpose

The purpose of this literature review is to critically examine the existing research on design costing for radar system remanufacturing in the maritime sector. Specifically, the review aims to identify the design-based costing platforms that are currently used to assess the critical cost drivers of product life cycle assessment, such as nonrecurring cost (NRC), unit production cost (UPC), and unit through-life cycle (UTC) cost. Additionally, the review will explore how to remanufacture products at the end-of-life based on cost trade-offs between different design routes, such as the decision to make or buy products, and how to develop a parametric cost estimation model to examine these trade-offs.

Overall, the goal of this review is to provide a comprehensive understanding of the design costing processes and techniques that are currently being used in the maritime sector for radar system remanufacturing, and to identify areas where further research and development may be needed to improve processes and techniques. In the context of radar system remanufacturing, there are several key terms that are important to understand. These include:

- Cost Trade-off: This refers to the process of balancing the costs and benefits of different design or manufacturing options in order to make informed decisions about which option is the most cost-effective.
- Design Costing: This refers to the process of estimating the costs associated with designing a product or system, including the costs of materials, labour, and resources.
- Nonrecurring Cost: This refers to the costs that are incurred only once, such as the cost of developing a new product or system.
- Unit Production Cost: This refers to the cost of producing a single unit of a product or system, including the costs of materials, labour, and resources.

Understanding these terms are important for organizations involved in the remanufacturing of radar systems, as they can help inform decision-making about the design and costing of these systems. By considering the trade-offs between different design options, estimating the costs of designing and producing the systems, and understanding the costs of nonrecurring and unit production, organizations can make informed decisions about how to optimize their operations and minimize costs while still producing high-quality systems.

Design Costing Remanufacturing

The ability to accurately predict the cost of a product is essential for the success of any project and business, as it plays a crucial role in winning customers and informing strategic decisions. In order to remain competitive and provide value to customers, companies must be able to predict the costs of their products throughout their life cycle. This is particularly important in the current context, where there is a societal need for sustainable, eco-friendly, and environmentally safe product life cycles [8,11,12]. In the context of radar system remanufacturing in the maritime sector, accurately predicting the costs of these systems is critical for ensuring that organizations can make informed decisions about their operations and remain competitive in the market. This literature review aims to contribute to the understanding of these issues and best practices in the context of radar system remanufacturing.

This research aims to provide a practical costing framework for companies seeking to improve the design of radar systems in order to solve warranty cost, failure issues, and make hardware improvements. By understanding and utilizing platforms for product design improvements, organizations can reduce overall life cycle costs during the critical post-design phase of these systems. In a cost-driven market, where customers are seeking low prices, reliability, and improved quality of remanufactured products, it is essential for organizations to consider remanufacturing issues in product design in order to remain competitive. Previous literature reviews have highlighted the importance of this issue [13, 1, 14, 15]. It is also important to note that a significant proportion of product life cycle costs are committed at the design stage, making it essential to use a cost estimation model based on the costing of design in order to compete with the quality management standards established by combining ISO standards for compliance. Additionally, environmental legislation in Europe is stringent, and organizations must adhere to standards such as ISO9001, Germany VDI 2243, and UK BSI8887 (British Standards Institution, 2010) [16,4 ,17,18,]. This literature review aims to contribute to the understanding of these issues and best practices in the context of radar system remanufacturing in the maritime sector.

Objectives

This literature review is based on a comprehensive review of relevant books, early access articles, standards, journals, and conference papers on the topic of design costing for radar system remanufacturing. From this review, only 52 papers were identified that explicitly addressed the topic of design to cost (DTC) remanufacturing, with a focus on the maritime sector, dating from 1998 to 2020. This research area is relatively new and understudied in the radar system maritime sector, and so there is a lack of available knowledge on this topic. The majority of papers reviewed in this study fell into one of the following categories:

➢ Identifying the key cost drivers for nonrecurring costs and unit production costs in the context of radar system remanufacturing in the maritime sector, including the use of design costing platforms to identify current production configurations and the cost drivers affecting the product life cycle, such as non-recurring cost (NRC), unit production cost (UPC), and unit through-life cycle (UTC) cost drivers.

➢ Examining the cost trade-offs between different product design routes in the context of remanufacturing, such as make or buy decisions, and developing parametric cost estimation models to help organizations make informed decisions about the most cost-effective design options.

➢ Providing decision-making support for engineering change order (ECO) requirements based on design costing and best practices for organizations seeking to improve the quality of products at the end-of-life stage.

Overall, the key objectives of this research are to contribute to the understanding of these issues and best practices in the context of radar system remanufacturing in the maritime sector. This literature review is based on a comprehensive review of relevant books, early access articles, standards, journals, and conference papers on the topic of design costing for radar system remanufacturing. The papers reviewed in this study have informed and influenced the final decision making process for this literature review. A parametric costing model can provide a template for innovation by showing the impact on costs throughout the entire life cycle and supporting decision-making in the design stage. The development of this model required establishing a flexible database and developing a set of parametric equations and alternative cost estimation methods. However, there is still much confusion in the literature about the definitions of remanufacturing for high-value products in the maritime sector. Key strategies for these products include identifying which products to reuse, redesigning to improve quality for remanufacturing, reworking vessels, and recycling [19,20,21,15]. This literature review aims to contribute to the understanding of these issues and best practices in the context of radar system remanufacturing in the maritime sector.

Organizations that provide maritime products, such as radar systems and navigation products, for the international commercial and defense sectors often design, remanufacture, and manufacture these products themselves. For a general overview of the remanufacturing literature, see [22,23]. For a review of how products should be designed for disassembly, see [16, 24, 25]. To learn about green product development and supply chain management in the context of production and product management, see [26,27, 28, 29]. These maritime products include navigation radar systems, electronic charts for vessels, heading marker devices, and integrated bridge systems. Maritime companies typically specialize in the design and development of these products and systems, including the mechanical, electronic, software, and system integration aspects.

This literature review focuses on the design and costing of radar system remanufacturing in the maritime sector. The products discussed in this review are typically manufactured by organizations that provide product lifecycle support for up to ten years. Most maritime standard products are designed to meet specific requirements, with technical work being done in-house and in production. Remanufacturing is often conducted by third-party business partners who undergo a supplier approval process based on compliance requirements. These partners are subject to country of concern checks to ensure their quality before becoming suppliers for maritime products for customers. The focus of this literature review is to understand the design and costing frameworks for improving the reliability and quality of remanufactured products in the maritime sector.

Taxonomy of Literature Review

This literature review aims to provide a systematic overview of the existing research on the design and costing of radar system remanufacturing in the maritime sector. By reviewing conference and journal papers on the subject over the past 30 years, we have identified a total of 59 papers related to design to cost (DTC). Of these papers, only six were published between 1990 and 1999, while 34 papers were published between 2000 and 2010 and 19 articles were published between 2010 and 2020. This trend reflects the increasing research interest in this topic as more industries have started adopting remanufacturing as a way to reduce costs and develop environmentally friendly solutions for end-of-life products and systems. The research conducted by these authors has laid the foundation for more specialized frameworks specific to the maritime sector, particularly in the area of radar systems. The taxonomy of the years in which the papers were published is presented in Table 1.

Table 1: Literature review taxonomy

Taxonomy of Years of Papers which was Published	
Reference	**Years**
(Ahmed, 1995; Amezquita et al., 1995; Ayres et al., 1997; Bras, 1999; Bras & McIntosh, 1999; Duverlie & Castelain, 1999; Ellram, 1999; Farag & El-Magd, 1992; Geiger & Dilts, 1996; Gupta et al., 1994; Harutunian et al., 1996; Ishii et al., 1994; Jarrod Beglinger, 1998; Konyk Jr. & Jin, 1997; McIntosh & Bras, 1998; Ou-Yang & Lin, 1997; Ries et al., 1999; Roulston, 1999; Sascha Haffner ARCHiVES J, 1993; Shu & Flowers, 1999)	1990-2000
(Ben-Arieh & Qian, 2003; Curran et al., 2004; Esawi & Ashby, 2003; W. Ijomah, 2002; W. L. Ijomah et al., 2004; Josias et al., 2004; Kimura et al., 2001; D.-H. Lee et al., 2001; Lindahl et al., 2003; NASA, 2008; Nasr & Thurston, 2006; Parkinson & Thompson, 2003; Ridley et al., 2019; Roy & Kerr, 2003; Scanlan et al., 2002; Shehab & Abdalla, 2001; Steinhilper, 2001; Sundin & Lindahl, 2008; Sundin, 2004; Younossi et al., 2001)	2000-2010
(Arundacahawat et al., 2013; Atia et al., 2017; Borchardt et al., 2011; Browning & Browning, 2013; Chou & Tai, 2010; Cui et al., 2017; Elahi & Yu, 2011; Erkoyuncu, 2011; Favi et al., 2016; Go et al., 2011; Gremyr & Fouquet, 2012; Hatcher et al., 2011, 2013; Herrmann et al., 2014; Hihn & Menzies, 2015; Hollweck, 2016; Keller et al., 2014; Meyer et al., 2012; Mittas et al., 2015; National Research Council, 2012; L. Newnes et al., 2011; Sanyé-Mengual et al., 2014; Schubel, 2012; Skubisz et al., 2015; Tang et al., 2013; Tobias & Boudreaux, 2011; Tongzhu Zhang et al., 2010; Yin R.K., 2009; Zhang et al., 2011; Zheng Yongqian et al., 2010)	2010-2020
(Bertoni & Bertoni, 2020; Campi et al., 2021; Chen et al., 2020; Doran et al., 2021; Favi et al., 2021; Francisco et al., 2020; Işıklı et al., 2020; Mandolini et al., 2020; Ning et al., 2020; Sordan et al., 2022; TCM Framework, 2022)	2020-2022

The aim of this literature review is to examine the current state of knowledge on the cost of design remanufacturing in the maritime sector, specifically for radar systems. The research aims to identify key cost drivers for non-recurring costs and unit production costs, as well as provide a design to cost template and best practices for organizations. Additionally, the review aims to examine cost trade-offs between different products and develop a parametric costing model to support decision-making in the design phase. The literature review will be based on findings from books, articles, standards, journals, and conference papers relevant to design costing remanufacturing. The review will focus on papers published between 1998 and 2020, with a particular emphasis on studies related to the maritime sector and radar systems.

The goal of this literature review is to identify and analyse current research on the cost of design and remanufacturing of radar systems for the maritime sector. The review aims to identify the key cost drivers, including non-recurring costs (NRC), unit production costs (UPC), and unit through-life cycle (UTC) costs, and to develop a parametric cost estimation model to analyse trade-offs between different product design routes, such as make or buy, in order to improve the quality and reduce the overall life cycle cost of remanufactured radar systems. The review also aims to provide best practices for organizations looking to remanufacture radar systems and to identify key areas for further research in this field.

Literature Review on the Cost of the Design Concept

The literature review found that lifecycle costing is a significant factor for industries such as consumer electronics, aerospace, automotive, electronics manufacturing, maritime, medical, and software product design. Remanufacturing is a profitable business opportunity because most raw materials can be reused, and energy savings can be translated to cost savings compared to newly manufactured products. Remanufacturing activities include disassembly, cleaning, inspection, rework, reassembly, and testing. The implementation of remanufacturing started in the automotive industry and has now been implemented in many other sectors. Design costing is critical for the success of any project and business. It plays a crucial role in winning customers, which is very important for the strategic decisions of any organization. Companies must predict the costs of their products throughout their lifecycle to remain competitive and provide value-added benefits for customers. Most product lifecycle costs are committed at the design stage, so a manufacturing cost estimation model based on the costing of design is necessary to compete in the cost-driven market where customers are looking for low prices, reliability, and improved quality of remanufactured products.

This literature review aims to provide a practical costing framework for companies that require knowledge and platforms for product design improvements to solve warranty cost and failure issues and make hardware improvements in the development and tools for reducing overall lifecycle costs during the critical post-design phase of radar systems [30, 1]. It also aims to review the key focus areas in navigational radar system design and develop end-of-life failure findings and conclusions. The review will examine the current state of the art in "Radar System" lifecycle performance and provide recommendations for where the research should go next in the maritime sector for vessels and systems. To achieve this, a series of questions about the costing of design manufacturing will be asked throughout the literature survey and existing literature on design to cost models, product design facilitates any steps involved in remanufacturing and product lifecycle support will be used for the benchmarking models based on a systematic literature review approach and design processes whereby an item designed for remanufacturing [31, 32, 13, 33]. The critical areas to be reviewed include radar application, cost estimates, design to cost, radar configuration, and cost trade-off areas.

Development of the Design Costing Model

To further understand the design costing of radar systems for remanufacturing in the maritime sector, three different costing methods were studied and developed: parametric estimation, analogy, and detailed. These methods were then reviewed and supported in technical workshops with cross-functional teams from various industries and sectors, including product design, production, supplier management, buyers, engineering, production engineers, and quality assurance. Some researchers have tried to list guidelines that could steer a design team toward reuse and re-manufacturability [34, 35, 36, 32].The workshops were used to validate the findings and suggest the best methodology to implement in the organization based on the literature review of these three different methods. This framework was developed to identify the most effective approach for improving the quality of radar systems through remanufacturing in the maritime sector. A literature review was conducted to identify the most effective method for costing the design of a radar system remanufacturing process. Three methods were analysed and developed: parametric estimation, analogy, and detailed. To validate the findings, technical workshops were held with cross-functional team members from various industries and sectors, including product design, production, engineering, and quality assurance. These workshops provided valuable insights and experiences to inform the development of a framework for implementing the chosen method within the organization.

Design Costing Model Validation

To verify and validate the costing template for the radar system design, the individual cost models and the overall cost trade-off tool will be utilized. The costing framework will be tested using different costing scenarios for different companies to validate its effectiveness. The remanufacturing process offers the opportunity for product cost reduction and continuous quality improvements throughout the life cycle of the product, as shown in Figure 1. The remanufacturing attribute feasibility space, as discussed by demonstrates the value-added benefits of an extended life cycle, such as design-to-cost remanufacturing [37-43]. This process is beneficial for organizations seeking to optimize the cost and quality of their products.

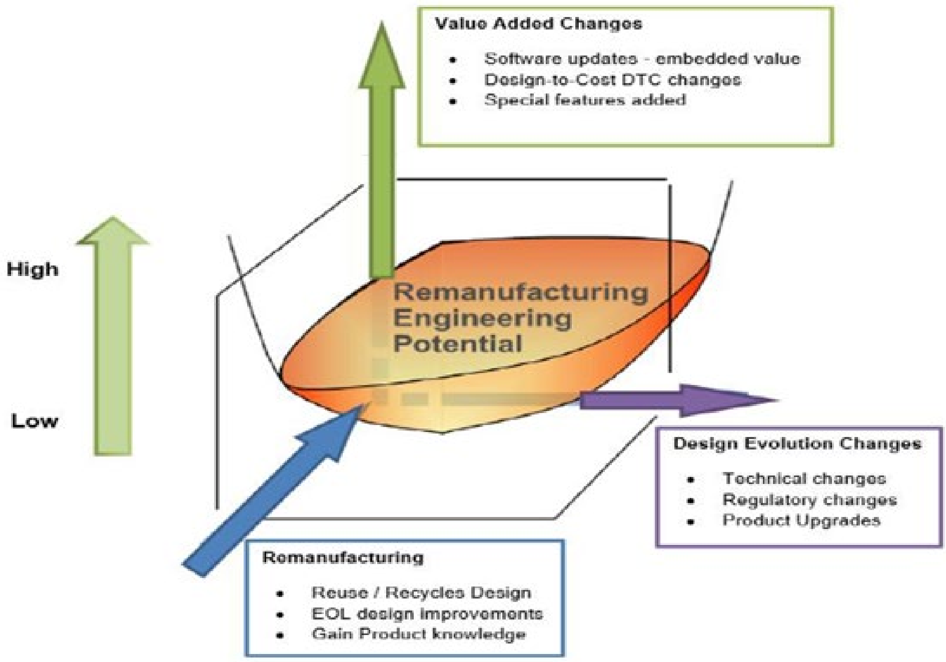

Figure 1: Remanufacturing attributes feasibility space
Source: (Oakdene Hollins, 2014)

There is a lack of research on the costing of design in the context of remanufacturing products in the maritime industry, which presents a challenge for organizations. Not all products in vessels are suitable for remanufacturing due to cost or environmental considerations [44-46]. While the decision-making process for end-of-life products in the maritime industry is beyond the scope of this literature review, companies can consider remanufacturing options when their production processes include specific capabilities, such as a reverse flow of used products and customer demand for remanufactured products [8, 19, 12, 7, 38, 48 ,8]. Design-to-cost is a cultural shift in organizational behavior, in which cost is given equal or greater weight than other factors. The goal of costing design is to minimize life cycle costs based on the process of remanufacturing, in which a used product is disassembled, rebuilt, and reassembled to function like a new unit with the same warranty and improved quality [49, 19, 7,50, 51, 52]. For high-value products and systems in the maritime sector, remanufacturing should be a consideration, and this design costing platform can provide benefits in the following scenarios:

- Original equipment manufacturers (OEMs) in the maritime industry may consider remanufacturing when they are responsible for repairing and refurbishing of used products.
- Independent, third-party remanufacturers who purchase used products to repair and resell them using reverse engineering to develop solutions. These companies have no direct connection with an OEM.

Participants of Design Costing Estimation

Cost estimation techniques can be divided into qualitative and quantitative approaches. The qualitative method is used when data is limited and the cost is not precise, but it can provide rough cost estimates for projects. The quantitative cost estimate involves a detailed analysis of the product design, which provides a more accurate estimate of cost. This literature review focuses on the use of parametric and analogy-based cost estimation techniques in design costing research. Different cost estimation methodologies are compared to identify and evaluate the most suitable approach for the organization to implement. In cases where costing data is not available, the Analogy Based Costing (ABC) model may be used.

According to this literature review and the proposed solution for the radar system, various parametric approaches are essential in identifying cost drivers and constructing a cost estimating model. Many studies have shown that approximately 80% of a product's cost is determined during the development phase, making it a crucial stage in the process. As such, it is important to be competitive when building a cost estimation model based on design costing.

The purpose of this literature review is to gather and review the current state of knowledge on the topic of design costing as it relates to radar systems. This includes information on cost estimation techniques, design to cost models, and cost trade-off information. The review was conducted using information accessed from university libraries and various database systems, such as Scopus, Science Direct, Web of Knowledge, and Search Point. In addition, in-house knowledge hubs of design and engineering organizations were consulted for cost design estimates and production cost reviews from the past three years. The literature review on design to cost identified the following cost estimation areas, as shown in Figure 2: a taxonomy of costing of design and cost estimation areas. This review highlights the widely used costing tools in other industries that are relevant to the focus area of design cost research.

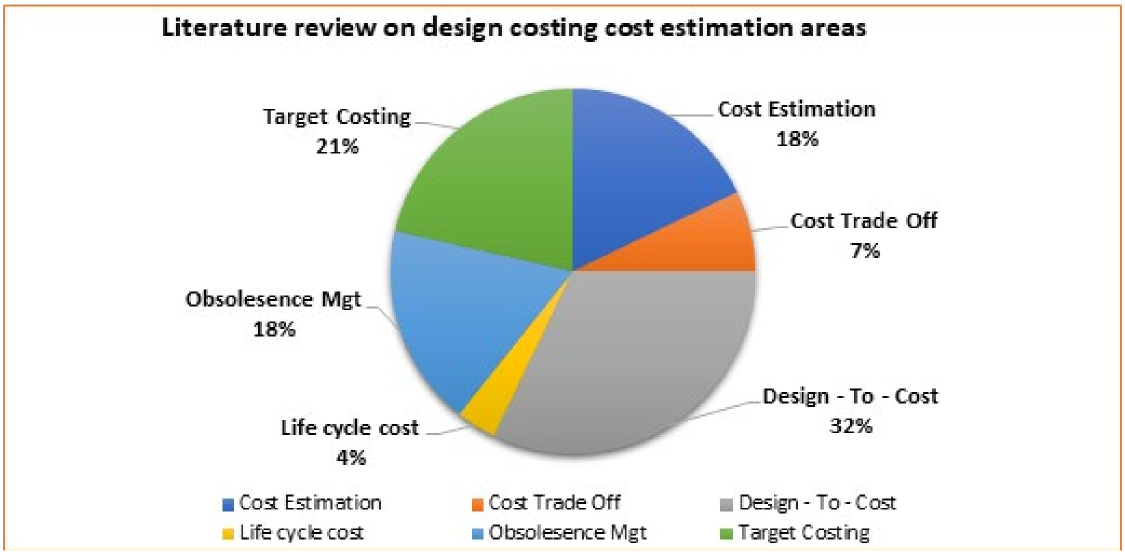

Figure 2: Taxonomy on design costing cost estimation areas

In the maritime industry, the remanufacturing process involves several steps beginning with the return of replaced units to the original manufacturer to claim warranties. Defective units are sorted, inspected, disassembled down to the core, cleaned at the component level, and tested at subassembly platforms before being completely reassembled according to the original design specifications and requirements. After-sales support includes various methods for supporting customers' products, including reuse, repair, remanufacturing, recycling, and reconditioning [53-56]. These methods are often ranked in a particular sequence.

Remanufactured products offer a cost-effective solution for high-end products in industries such as maritime, automotive, rail, and aerospace. They are ideal for upgrading old systems and providing end of life (EOL) solutions for customers. When customers need to add backup spares, expand, or upgrade their systems, certified remanufactured products can offer cost-effective and environmentally friendly alternatives to purchasing new units. These products are factory-remade by the OEM (Original Equipment Manufacturer) and come with all the necessary accessories for installation. Remanufactured products provide the following benefits:

• Cost-effective alternative to purchasing new equipment or option for backup spares
• Comprehensive 12-month parts and workmanship warranty

Managing the entire product life cycle support of a radar system's application and field issues, including decommissioning activities, is critical for the success of remanufacturing. As shown in Table 2, organization must consider how the product design can facilitate remanufacturing processes to maximize the value of the end of life product.

Table 2: Product design to facilitate processes required for remanufacturing

Product design changes to facilitate process improvements for remanufacturing		
Process	**Examples of Design Tips**	**Reasons for design change options**
Transportation	Avoid protrusion outside of the regular geometric design size.	Minimise damage in transit
Disassembly	Reduce quantity and variety of changes in the fasteners Use standardised fasteners	Reduce the tools required for disassembly Reduce disassembly time
Sorting	Use either identical or grossly dissimilar parts.	Reduce the effort required to discern parts
Cleaning	Avoid geometries shapes that trap dirt and use sharp grooves and recesses. Use appropriate material types, textures, and colour	Maximise usage of clean tools and fluids. Reduce dirt and damaged parts incurred during the cleaning process
Assessment	Accurately and explicitly indicate a part's remaining useful life	Reduce the effort required in assessing the reusability of components (create Charts and Testing Templates to validate the parts)
Refurbishment	Design parts that do not fail in products. Keep an eye on the wear and failure in removable or changeable parts, like the use of inserts and sleeves	Reduce requirements for labour time to remanufacturing or offer capital intensive to customers to offer refurbishment services

Costing Methods Analysis

The development of a design costing model for remanufacturing radar systems in the maritime sector requires an understanding of how to design for improved quality and reuse. Researchers have attempted to identify guidelines that could direct a design towards re-manufacturability [49, 57, 34, 35, 36, 58, 32]. These guidelines outline the types of materials and design structures that may pose challenges during production. To obtain a complete picture of the life cycle costs of radar systems, including production, end of life, and reuse and remanufacturing, it is necessary to gather relevant information and data. Additionally, a new understanding of the different configuration possibilities and capabilities of radar systems can be developed and validated using other costing models. Three different costing methods were studied and developed: parametric estimation, analogy, and detailed. Technical workshops were also held to review and support the costing solutions and validate the findings. These workshops included cross-functional team members from product design, production, supplier management, engineering, production engineering, quality assurance, and buyers, who brought their experiences from various industries and sectors to support the design costing platform. Based on these workshops, suggested methodologies were used to develop a framework from the literature review, which identified the best way to implement in the organization from the three different methods.

The costing of design research in the maritime industry has mainly focused on understanding the root causes of failures in marine products and systems, and identifying opportunities for remanufacturing at the end of their life. Researchers have used engineering tools, quality methods, and prototype testing to redesign and improve the cost-effectiveness of these products. There are various costing frameworks and methods available for the maritime sector to consider when making decisions about re-manufacturability and prioritization, including mathematical models, software tools, and static references. In recent years, there has been a shift towards using cost-based approaches for decision-making in various industries, and towards design methods that focus on improving the qualitative guidance provided to designers. The most cost-effective design changes are often made early in the design process, when there is less technical data available and fewer decisions have been made. The literature review of product renewal and maintenance cost estimation in various industries has classified these costing techniques or approaches into a taxonomy, as shown in Table 3.

Table 3: Literature review on costing of design papers

No.	Author	Year	Costing Tool	Costing Model Framework	Format	Use in Industry
1	Leo Egghe and Ronald Rousseau	2000	Obsolescence Mgt.	Obs., "as the possible decline of usefulness over time….".	Calculations	No
2	A. Meyer et al., L. Pretorius, JHC. Pretorius	2004	Obsolescence Mgt.	Managers and designers were unaware of how to manage obsolescence and only had to react once it happened to find a "quick fix" solution until recently.	Calculation / Software	Yes

3	Howard, M. A.	2002	Obsolescence Mgt.	Components Obsolescence issue happens everywhere, not just in the electronics	Concept	No
4	Singh et al.	2002	Obsolescence Mgt.	advice is to mitigate obsolescence issues more proactively to minimise obsolescence impact on product	Concept	Yes
5	Josias et al.	2004	Cost Trade-Off	Risk assessment based on Obsolescence components	Calculations	No
6	Romero Rojo	2010	Obsolescence Mgt.	It is essential to consider the level of proactivity depending on the initial risk assessment at up component level.	Reference	No
7	Romero Rojo	2010	Obsolescence Mgt.	The mitigation approach deals with actions taken to minimise the impact.	Paper / Software	Yes
8	Elahi, G.	2011	Cost Trade-Off	Said following Three usual problems encountered while working on a trade-off process: Extensive data collection, Extraction of stakeholders' Preferences & Complexity Scalability	Concept	No
9	Haas and Wortruba	1976	Cost Trade-Off	Accurate comparative cost analysis is necessary for developing marketing strategies in a make or buy situation	Calculations	No
10	NASA	2008	Life cycle cost	A Total Cost of Design, development, deployment, field, operation, maintenance, and disposal of a system of the life cycle	Calculation	Yes
11	Shehab et al.	2001	Cost Estimation	Companies think about the cost of material compared to superior quality	Concept	No
12	Roy and Kerr	2003	Cost Estimation	Suggest Two ways to classify costs; 1/. First by Type of Cost - Recurring cost (Lab, Materials & Subcontracts), Production Floor cost & R&D 2/. Cost by the functions such as Production Cost, Operating Expenses & Non-Operating Expenses	Calculation / Software	Yes

13	Niazi et al.	2006	Cost Estimation	separates the cost estimation by their qualitative or quantitative aspects	Concept	No
14	Chauvet and Collier	2006	Cost Estimation	Not only one method is suitable for the whole life cycle cost. Each one is applicable in a specific context	Paper	No
15	Daniel Ling	2002-05	Cost Estimation	Cost estimating is covered with predicting the total cost of a project by estimating	Reference	No
16	Courtney et al.	2009	DESIGN-TO-COST	Cost is given an equal or more significant weighting in the trade-off decisions	Software	No
17	Ahmed, N.	1995	DESIGN-TO-COST	DESIGN-TO-COST is to minimise Life Cycle Costs by looking at the design process	Paper / Calculation	No
18	Amedo, S. et al.	2011	DESIGN-TO-COST	Usually, around 70% of the Life Cycle Cost of a project is committed during its design phase	Calculation	Yes
19	Williamson, N.	1994	DESIGN-TO-COST	Cost estimation is important in any design-to-cost process	Software	No
20	Ellram	2000	Target Costing	Target costing is a tool for sustaining manufacturers to remain competitive	Calculation	No
21	Dekker and Smidt	2003	Target Costing	use reverse costing methodology in which selling price and OM determine the Manufacturing Cost	Concept	No
22	Cooper and Slagmulder	2000	Target Costing	Product cost as an input rather than an outcome of a product development process Whole Life Cycle Cost: a new approach	Concept	No
23	Jariri. F.; Zegordi. SH.	2008	Target Costing	Quality Development Function (QDF) and Value Engineering (VE) were used for the target costing of SMEs	Software	No
24	Ben-Arieh, D; Qian, Li.	2001	Target Costing	Allow costing of a product from Elementary tasks, operations, and activities with known costs factors	Calculation	No

25	Gunasekaran and Sarhadi	1998	Target Costing	Traces the cost via activities performed on the cost objectives in Production & Service tasks Activity-based cost management for the design and development stage	Calculation	No
26	Headquarters US Air Force	2010	DESIGN-TO-COST	Developed a project on integrating performance, scheduling, and cost of ground-based radars	Calculation	No
27	John, F. Roulston	2002	DESIGN-TO-COST	Differentiates the radar into two different systems: the transduction part & computing part	Software / Calculation	Yes
28	Sommerville, I.	2004	DESIGN-TO-COST	Four different techniques are used for the DESIGN-TO-COST cost estimation: Algorithmic, Expert, Analogy and Parkison	Concept	No
29	Weber, M., Hoon Kwak	2004	DESIGN-TO-COST	Map the current stages and was able to create different cost models for the other processes	Calculation	No
30	Dhilon	2010	DESIGN-TO-COST	studies weather radars, and he was able to calculate the Life Cycle Cost of the radar	Calculation	Yes

Literature Review Framework

Design costing remains largely within the academic realm, with little evidence of its use in industry today [59-62 ,14,63]. OEMs are often hesitant to support remanufacturing by third-party suppliers due to concerns about losing intellectual property (IP) and sharing in-house manufacturing process tools. This research aims to support decision-making on costing unknown issues for OEMs considering the introduction of remanufacturing based on an investigation of failures at the end of life. It is important to address problems before remanufacturing, as was done with four radar system products in this research, in order to make products suitable for reuse in a second lifecycle in vessels. The literature review framework is shown in Figure 3.

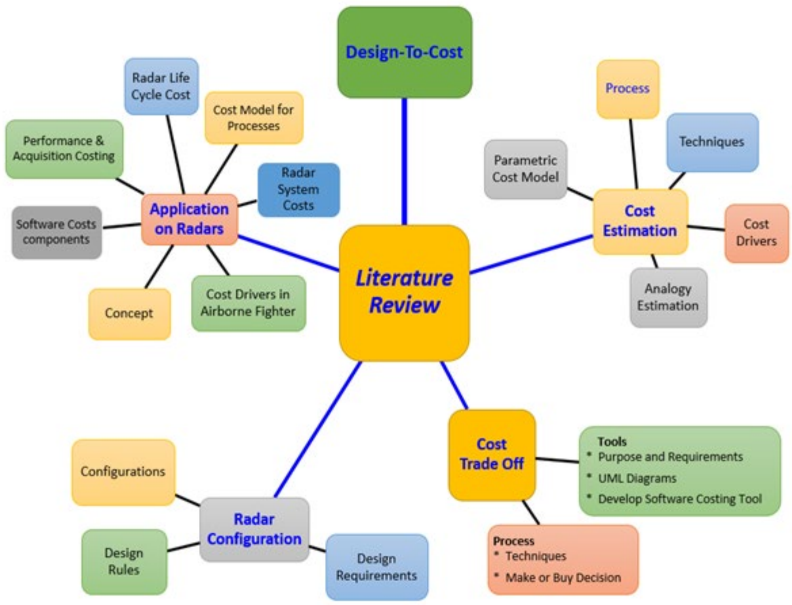

Figure 3: Literature Review Framework

One key issue in the literature on design costing is the complexity of maritime products such as S-band radar systems, which may not be well-suited for application in academic design aids due to a lack of lifecycle knowledge. Additionally, many of these aids are only suitable for use late in the design process, while cost-effective solutions are often needed at the very early stages of prototype decision-making for product design.

Another trend in the literature on design costing is the proposal to use existing knowledge about costing frameworks for design concepts that are relevant to enhancing re-manufacturability based on renewal and maintenance. Table 4 presents cost estimation techniques for maintenance cost estimation approaches.

Marine products require careful attention to quality in design and manufacturing. Standardizing procedures and using online service support guides with standardized parts kits has allowed for the rationalization of component costs using cost estimation techniques to develop the most effective approach.

Table 4: Maintenance Cost Estimation Approaches

Maintenance Cost Estimation Approaches	
Reference	**Techniques / Approaches**
(Dhillon, 2009; Madhavan et al., 2008; NASA, 2008; L. Newnes et al., 2011; Prince, 2002; Roy & Kerr, 2003; Younossi et al., 2001)	Bottom-Up
(Atia et al., 2017; Ben-Arieh, 2002; Campi et al., 2021; Duverlie & Castelain, 1999; Dysert, 2008; Farrington, 2005; Qian & Ben-Arieh, 2008; R. Watson & Management Program, 2004)	Parametric
(Ahmed, 1995; Curran et al., 2007; Dhillon, 2009; Herrmann et al., 2014; Ishii et al., 1994; A. King & Barker, 2007; Nasr & Thurston, 2006; L. Newnes et al., 2011; L. B. Newnes et al., 2008; O'Hare et al., 2007; Rush & Roy, 2000; Shu & Flowers, 1999; Vezzoli & Sciama, 2006)	Life Cycle Cost Analysis
(Ahmed, 1995; Amezquita et al., 1995; Dhillon, 2009; Duverlie & Castelain, 1999; Ellram, 1999; Erik ten Brinke, 2002; Esawi & Ashby, 2003; Farag & El-Magd, 1992; Geiger & Dilts, 1996; Gupta et al., 1994; Ishii et al., 1994; Lindahl et al., 2003; L. Newnes et al., 2011; Parkinson & Thompson, 2003; Roy & Kerr, 2003; Zheng Yongqian et al., 2010)	Equations / Expressions

Another theme in the research trends on design costing and renewal and maintenance cost estimation frameworks is the use of different methods by different industrial sectors, as shown in Table 5. The literature presents case studies of cost estimation frameworks used by various industrial sectors and products. However, many papers do not specify the methodology used to arrive at their findings. In this research, four case studies of maritime radar system parts with OEMs were conducted to redesign products. These case studies were chosen as the most popular approach.

Therefore, to make changes in the manufacturing to improve quality for the remanufacturing of the radar systems with sea trails to validate the solutions developed by the end of life root cause investigation develop solutions. Because case studies are considered appropriate because of the lack of maritime products, previous knowledge is available about the maritime sector subject area . However, some of the early papers explained the cost estimations from 1978 to 1997 and adopted the framework of quantitative analysis for the survey approach [13, 64].

Renewal Cost Estimation Industries

Table 5 presents a taxonomy of the literature review on product maintenance cost estimation based on different industries and domains for cost estimation. This table shows the various industries and domains that have been studied in the literature on renewal cost estimation.

Table 5: Renewal cost estimation industries

Renewal Cost Estimating Industries	
Reference	**Domains / Industries**
(Choi et al., 2007; Curran et al., 2004; el Wazziki & Ngo, 2019; Price et al., 2006; Safavi et al., 2013; K. Wang et al., 2002; P. Watson et al., 2006)	Aerospace
(Hatcher et al., 2013; Ip et al., 2018; Johansson, 2002; Plant et al., 2010; Subramoniam et al., 2009; Sundin & Lindahl, 2008)	Agriculture / Plant
(Eisenhardt, 1989; Ip et al., 2018; Oakdene Hollins, 2014; Sundin & Lindahl, 2008)	Buildings / Facilities
(Aslanlar et al., 2008; A. M. King & Burgess, 2005; NASA, 2008; Plant et al., 2010; Prince, 2002; Skubisz et al., 2015)	Factory / Plants
(Aslanlar et al., 2008; Geiger & Dilts, 1996; Go et al., 2011; Lam et al., 2000; Seitz & Wells, 2006; Subramoniam et al., 2009; Tongzhu Zhang et al., 2010; Yüksel, 2010)	Automotivevehicles

(Elahi & Yu, 2011; Geiger & Dilts, 1996; Harutunian et al., 1996; Hihn & Menzies, 2015; Ian Sommerville, 2004; W. L. Ijomah et al., 2004; Madhavan et al., 2008; Mittas et al., 2015; Pete Sawyer, 2007; Schubel, 2012)	Software / Automated

The purpose of this literature review is to explore the current state of knowledge on the topic of design costing in the context of radar system remanufacturing in the maritime industry. In order to do so, various databases and library resources were consulted, including Scopus, Science Direct, and Web of Knowledge. The review focused on research published in the past three years and covered topics such as design costing models, validation of those models, participants in design cost estimation, and costing methods analysis.

The literature review found that there has been relatively little research on design costing in the context of maritime products, and specifically on the remanufacturing of those products. It also identified a trend towards using cost-based solutions for decision-making in various industries, as well as a shift towards using design methods and improving the quality of qualitative solutions to guide designers. In terms of the costing methods analyzed, the literature review found that parametric approaches are critical in identifying cost drivers and building a cost estimation model. It also highlighted the importance of early consideration of cost in the design process, as approximately 80% of a product's cost is typically determined during the development phase. The review also discussed the steps involved in the remanufacturing process for maritime products and the importance of managing the end of life of those products in order to maximize their reuse. It also identified the need for redesign of products before remanufacturing in order to address any issues that may have caused the product to reach its end of life in the first place.

Overall, the literature review found that there is a lack of research on design costing for the remanufacturing of maritime products, and that more work needs to be done in this area in order to support decision-making and improve the remanufacturing process for these products. Research from the past 30 years has been conducted mainly by European countries such as Sweden, France, Germany, and the UK. A change in demographics coincides with an increase in the number of papers concerning the environmental impact of remanufacturing, which coincides with the introduction of stricter environmental legislation across Europe.

"Design for Cost remanufacturing platform with Quality Controls"

1.	Conferences	6.014
2.	Journals	1165
3.	Early Access Articles	52
4.	Books	16
5.	Standards	03

An overview on Costing of Design Remanufacturing Model is reviewed from different sectors; how other sectors' studies overlap with the supporting links of PDFs. As shown in the following Link: Open Knowledge Mapping.

- https://openknowledgemaps.org/map/3399b-9f0812a6d106493551046a2e7c2

A literature review of the design costing papers reviews has shown the following KPIs (Key Performance Indicators) in Figure 4: Literature review on the costing of design trends.

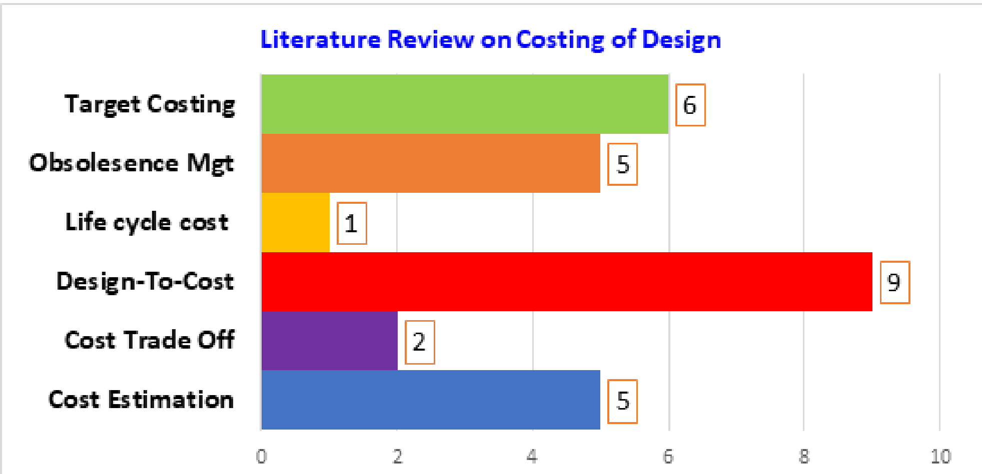

Figure 4: Literature review on the costing of design trends

Costing Methods

"Costing for Design" is a process in which cost is given equal or greater consideration in decision-making during the design phase of a product or system. This approach, known as product life costing, aims to minimize the total cost of ownership over the product's lifetime by carefully considering cost in the design process [49, 65]. Research has shown that approximately 70% of a product's life cycle cost is typically determined during its design phase, as illustrated in Figure 5: The evolution of cost [66, 67].

To meet cost estimation requirements, a design costing template is often used in the system design process. This technique involves setting realistic but rigorous cost targets and working towards achieving them [68-70]. The importance of cost management is emphasized throughout the product design improvement and production process change reviews [68, 69].

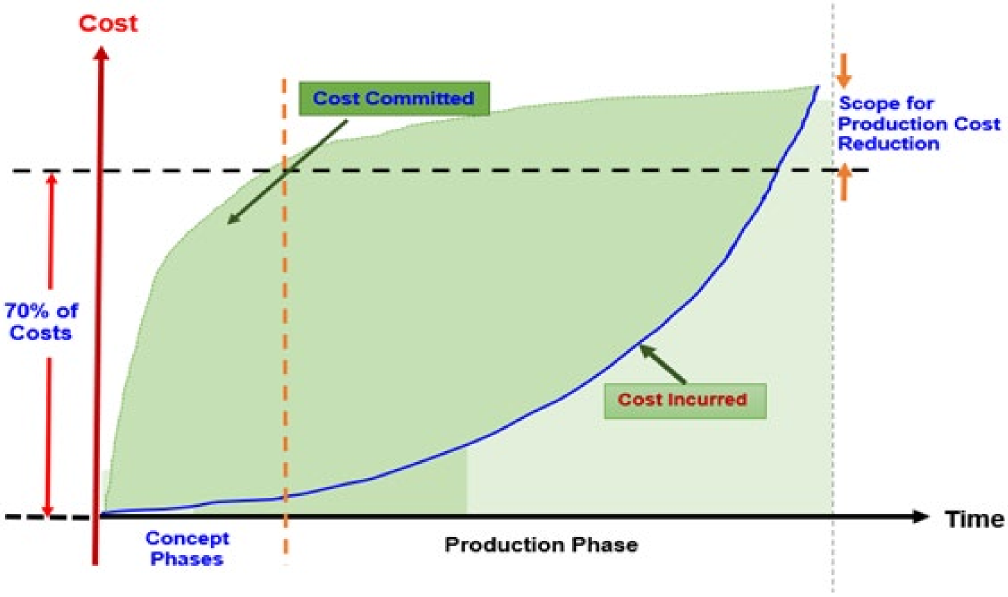

Figure 5: Evolution of Cost Source: (Rush & Roy, 2000)

Accurate cost estimation is a critical component of the design costing process [71,72,10,73,]. Traditionally, target cost and activity-based costing (ABC) approaches have been used for design costing [71]. These methods allow designers to assess the costs of different design options and make informed trade-off decisions during the design process.

Target Costing

Target costing is a cost management technique that is used to control product cost drivers throughout the design stage. It is particularly important for remanufacturers to use target costing in order to remain competitive, meet quality standards, and meet customer expectations [74, 75]. Target costing employs a reverse costing methodology, in which the selling price and required profit margin are used to determine the allowable cost for manufacturing a new or existing product [76-79]. This approach is different from traditional cost management methods, as it considers product costs as an input rather than an outcome of the development process [80-82]. Integrated remanufacturing organizations may use operation management costing tools such as quality development function (QDF) and value engineering (VE) for target costing in small and medium-sized enterprises (SMEs) [83, 84].

Activity Based Costing

Activity-based costing (ABC) is a method used to evaluate the cost of a product or service by decomposing it into critical tasks, operations, or activities and identifying the cost drivers associated with each [85-87]. This approach allows for traceability of costs by linking them to specific activities based on predetermined cost objectives. Additionally, the use of ABC can lead to the classification of activities as value-added or non-value-added, which can aid in identifying and eliminating non-value-added tasks [85, 86].

Cost Estimation

It is important for companies to consider all the cost drivers they incur in order to price their products and services competitively and ensure superior quality [88, 89, 82,]. This research began with an analysis of end-of-life radar systems returned to warehouses in the Netherlands, where the yearly cost of scraped end-of-life maritime products was found to be half a million euros. The aim of this research was to provide new insights into the formation of a design costing platform for cost estimation of radar systems, with a focus on improving the lifecycle cost of maritime products through design improvements and the implementation of a quality framework solution. This research has generated new knowledge based on best practices for design costing platforms and has developed a prototype parametric cost trade-off tool for reducing warranty costs and overall life cycle costs of radar systems.

Effective cost estimation techniques are crucial for companies to have full control over the price of their products [90, 67,91]. These techniques should take into account the following types of cost drivers:

➢ Recurring cost drivers, such as labour, raw materials, and sub-suppliers or contracts.

➢ Nonrecurring cost drivers, such as design and development changes using test jigs or platforms.

➢ Overhead costs, including administrative expenses, research and development costs, health insurance, and operational costs.

Cost driver based on functions depicted cost, as shown in Table 6: Cost classification by function [92, 93].

Table 6: Cost Classification by Function Source: (Roy & Kerr, 2003)

COST CLASSIFICATION BY FUNCTIONS / DEPARTMENTS
Production Costs / Remanufacturing Cost
• Raw Material Consumed
• Labour
• Manufacturing Overheads
Operating Expenses
• Selling Product Cost
• Administration Cost
Non-Operating Cost
• Financial Charges
• Donations

Cost Estimation Techniques

The Association for the Advancement of Cost Engineering (AACE) defines cost estimation as a "predictive process used to quantify the cost and price of resources required for the scope of an asset investment option, activity, or project" [94]. Cost estimation techniques can be classified as qualitative or quantitative, as shown in Figure 6: Cost Estimation Technique Classification [95, 96]. Qualitative techniques rely on subjective judgment and expert opinion, while quantitative techniques involve the use of numerical data and statistical analysis.

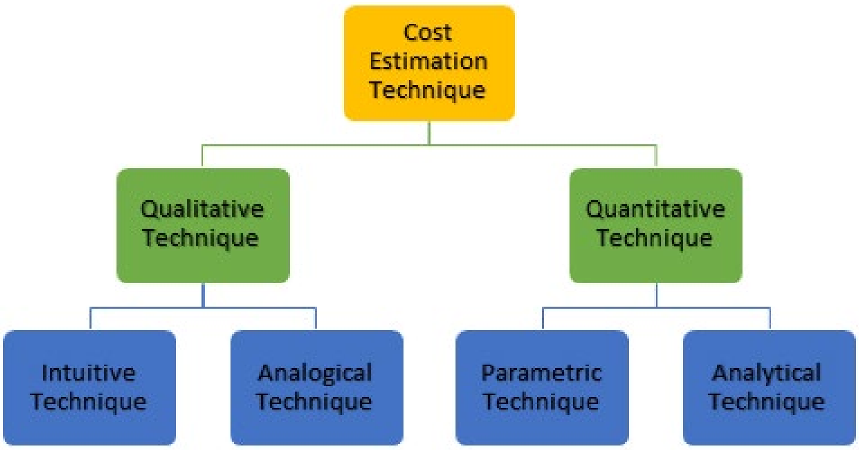

Figure 6: Cost Estimation Technique Classification Source:

Costing research has emphasized that no single method is suitable for the entire lifecycle of a product. Instead, different methods are appropriate for different contexts within an organization [65, 82]. It is important for companies to choose the most appropriate cost estimation technique for their specific needs and goals. Qualitative cost estimation techniques rely on subjective judgment and expert opinion rather than numerical data and statistical analysis. These techniques are often used for comparative analysis of the manufacturing and remanufacturing lifecycle costs of a product, using the known original manufacturing costs as a reference. There are two main types of qualitative cost estimation techniques:

➢ Expert judgment: This technique involves seeking the input and expertise of individuals who have knowledge and experience in the specific area being costed.

➢ Analogous estimation: This technique involves using the cost of a similar product or project as a basis for estimating the cost of the current product or project.

An Intuitive Technique

An intuitive cost estimation technique is one that primarily relies on the production engineering knowledge and experience of the manufacturing processes, as well as the understanding of the estimators in the supply chain management (SCM) team to validate the costing of suppliers or internal processes. This technique is often based on the collective knowledge and expertise of the SCM team, rather than on numerical data or statistical analysis.

An Analogical Technique

An analogous cost estimation technique is one that is based on the known data and historical lifecycle cost of production and product support in the supply chain management (SCM) team, using the similarities of the remanufacturing processes as a basis for cost estimation. This technique relies on the use of past data and experience to predict the cost of similar processes in the current product or project. It is often used when there is a lack of detailed information or data available for more precise cost estimation methods.

Quantitative Technique

The quantitative technique is a method of estimating the cost of remanufacturing a product through detailed analysis of the product design and supply chain management (SCM) availability of raw materials. This technique, known as the top-down approach, is commonly used in early strategic planning for remanufacturing. According to the quantitative technique consists of "cost estimating relationships and other parametric estimating functions that provide a logical and repeatable relationship between independent and dependent variables" [97, 94, 87]. Another technique, known as the bottom-up approach, involves decomposing the system into sub-products or production processes, sub-assemblies, and other resources required for manufacturing or remanufacturing the product [98, 99, 57, 77, 100, 75]. This approach can provide a more accurate cost estimate, but it is time-consuming. Overall, the use of quantitative techniques in the remanufacturing of products requires a significant amount of expertise in product manufacturing and costing, but it can lead to very accurate cost estimations.

An analysis technique consists of decomposing integrated systems into sub-products or production processes, sub-assemblies of different types, and requiring other suppliers or resources to manufacture or remanufacture the product [98, 99, 57, 100, 101]. It is known as the bottom-up approach, which provides an improved cost estimate, but it can be very time-consuming. Therefore, quantitative techniques are time-consuming due to the type of raw data required for the mathematical analysis, which involves expertise in product manufacturing and costing knowledge but leads to very accurate cost estimation.

Cost Estimation Process

Cost estimation involves predicting the total cost of a project by estimating the actual costs of all elements, including labor, materials, and equipment, in advance [102-105]. The National Aeronautics and Space Administration (NASA) defines project Life Cycle Cost Estimation (LCCE) as "a full cost accounting of all resources necessary to design, develop, deploy, field, operate, maintain, and dispose of systems over their lifetime" [106]. As shown in Table 7, the cost estimation process is a key stage in the NASA cost estimation process [106, 103].

Table 7: Cost Estimation Process Source:

NASA Cost Estimation Framework				
Stage A: Product Definition				
1. Initial Customer Request and Understand of Products and Systems specifications.	2. Build or Obtain Products			3. Obtain/Participate in the Development of Products Technical Description
Stage B: Cost Methodology				
4. Develop Customer req. by understanding rules and assumptions	5. Cost Estimation Methodology	6. Select Cost vs Build Model		7. Collect required Data and Normalise it
Stage C: Estimate				
8. Develop Point Estimate	9. Develop and Incorporate Cost Risk Asses	10. Document Cost estimates	11. Present Cost Estimate Results	12. Keep the Cost Estimate up to date regularly

The National Aeronautics and Space Administration developed costing process and implemented the following three strategies for the cost estimation process for production and remanufacturing of products [106, 103]:

➢ Product Definition: Understanding the project being estimated is crucial. This involves gathering data, building a work breakdown structure, and obtaining a technical description of the product.
➢ Cost Methodology: This process involves creating the approach and framework for the estimate by developing ground rules and assumptions, selecting an estimation method, building the cost model, and normalizing the required data to validate it.
➢ Estimating process: This involves conducting, presenting, and maintaining the cost estimate.

These steps are essential for accurately estimating the cost of the design and specification of a product. When working on trade-offs during the production and remanufacturing process, it is common to encounter issues and problems such as losing one aspect, like quality, in favour of cost-saving benefits identified the following issues that can arise during the trade-off process [65, 31, 39]:
➢ Data collection is a major issue when considering multiple life cycle support and cost drivers.
➢ Determining stakeholders' preferences for data analysis can be challenging.
➢ The lack of actual data and unknown factors can increase the complexity of the study, affecting sample scalability.

Overall, these issues can make the trade-off process difficult, particularly when it comes to extensive production and life cycle cost drivers.

To address these issues, it is critical to follow precise techniques for decision-making, such as the analytical hierarchy process (AHP) [65, 107]. AHP involves pairwise comparisons of decision-making elements in the remanufacturing process to assess the effectiveness of quality and cost. Swaps, or chain trading from one decision criterion to another, are also commonly used by key stakeholders to improve one standard in exchange for reducing another [108, 109].

Future Work of Design Costing Research

The initial purpose of this research was to create a cost estimation model for radar systems that could accurately estimate costs using complex parametric equations (such as power-law). However, the lack of necessary data has limited the model's accuracy to equations of lesser complexity based on linear logic. Despite this limitation, the key benefit of this research for the organization is the rapid understanding of design costing and quality management techniques for the remanufacturing of products. This will enable maritime companies to continue improving their outcomes [110-112, 31, 113, 114]. Future work in this area should focus on acquiring more data to develop a more accurate cost estimation model.

This literature review did not find a significant amount of research on the future of design costing in the maritime sector. Some papers did mention that further research is needed and many papers focused on developing cost estimation solutions for different sectors based on their specific needs. There is a lack of fully defined design costing frameworks and methods in the maritime industry, and further research is needed to analyze the costs of other maritime products and systems.

A parametric decision-making tool has been developed that has the potential to significantly improve the cost estimation process for companies in the maritime sector. This tool provides the following benefits:

- ➢ A knowledge hub for product costing was created to develop the design-to-cost model.
- ➢ The cost trade-off tool can reduce costs for future products and configurations.
- ➢ The tool can help with the "Design or Buy" decision by comparing the cost of building blocks in both cases.
- ➢ It improves cost data management by allowing all data to be entered into a database and updated with new products, building blocks, and costs.

In summary, the benchmarking output provided valuable knowledge on design costing. It gave an overview of the efforts that other companies are putting into this area and the value-added benefits of reducing warranty costs and improving product reliability. The design costing tool provides guidance for companies on how to implement it in the long term and how high-value remanufacturers can produce a higher quality product.

Cost Drivers of Radar System

Radar systems can be divided into transduction and computing parts [115, 54, 55, 56]. Each part consists of various sub-assemblies, features, and components with different cost drivers, as shown in Table 8.

Table 8: Radar System Parts Source: (Roulston, 1999)

Transduction Part	Computing Part
• Analogue attributes	• Hardware
• Transmission and reception	• Software Operating System
• Generation of frequencies	• Navigation Charts (Sea Maps)
• Pulse forms, and waves forms	• Power Supply
• Conversion of Radar signals into digital Board	• Connectivity (Network)

Procurement is a critical cost driver for the manufacturing and development of any product, and companies in the UK and Europe prioritize a competitive supply chain. Other cost drivers for radar systems include hardware parts such as "signal fidelity," which can be costly. The analog to digital conversion (ADC) can also push the unit towards state-of-the-art performance, but at a disproportionate additional cost. The transduction and computation parts of the radar system, along with displays, have different life cycle characteristics. The fidelity of the waveforms generated during the transmission and reception functions of the radar system may affect the requirements for selecting the desired target, which in turn affects the antenna (scanner capabilities), the quality of the transmit/receive (T/R) modules (equal fidelity rate), and the affordable fidelity. Hardware accounts for less than 25% of the non-recurring engineering cost and design and development cost of the processing parts of the radar system. The short life cycle of radar products in vessels is a technical reason for the hardware base of radar processing on digital signal processing (DSP) and central processing unit (CPU) devices.

he cost consequences of more end-of-life cycle changes due to the obsolescence of parts will be needed during the next five years of the product life to improve radar quality. Software changes account for nonrecurring costs (NRC). The characteristics of the critical software cost driver are that there are no tangible benefits or returns in the production phase of the radar system. Software changes are often a major source of cost overruns and potential development losses that are not recoverable as part of continuous product improvements. An overview of the software lifecycle changes costs for a radar system should be provided, along with information on how payment is made. Customers who use the software should be charged by the hour. The key conclusion of this literature review is that production costs are dominated by components, which has led to long-term supply chain agreements with sub-suppliers to maintain stable supply and acceptable costs. The transduction and computation parts of the radar system have different lifecycle characteristics, and it is important for product line managers to adopt policies that provide support to end-users and customers in vessels to reduce overall system costs. Therefore, remanufacturing and upgrade policies should be adaptable for multiple life cycles of the radar system on the production floor by manufacturers to be used in vessels. Obsolescence management is crucial for high-value parts which refer to the potential decline in usefulness of components over time [116, 117]. In the past, managers and designers were unaware of obsolescence management and only reacted to it when it happened, finding quick solutions [117, 118].

Therefore, it is advisable to proactively mitigate obsolescence issues to minimize their impact [117, 118]. For obsolescence resolution, it is important to consider the level of proactivity based on the initial risk assessment by the design engineering team at the component level, the probability of the component becoming obsolete, and the resulting impact on cost [116]. Mitigation strategies involve taking actions in three main areas: the supply chain, design for obsolescence, and planning replacement solution options by design team [119-123, 96]. When obsolescence of parts and materials begins to occur, the resolution approach is to replace the elements with the same component type based on the form-fit-function (FFF) replacement method, once it has been validated by the design engineering team. Emulation and redesign work are also done by the product design team to validate the replacement .

Radar Costing Analysis

The costing platform integrates performance, scheduling, and cost for a ground-based radar system. The US Air Force Headquarters developed a framework for integrating performance, scheduling, and cost for ground-based radars [70]. The purpose of the research was to create a capability to support a space fence cost estimate for the Air Force Cost Analysis Agency (AFCAA). The research involved developing a radar cost model based on normalised cost data, technical data, schedule data, and programmatic data for the radar. In the Air Force study, the cost model estimates the development and production cost of the radar system, including performance, design parameters of the radar system, and sub-assemblies.

Examples of the Radar CER are:

- Radar Hardware:
  $\text{Cost} = A\ (\text{Power})^{B}\ (\text{Aperture})^{C}\ (\text{Frequency})^{D}(\text{Program Type})$
- T/R Module Hardware:
  $\text{Cost} = A\ (\text{Power})^{B}\ (\text{Frequency})^{C}(\text{Qty})$
- Radar Support:
  Cost = A (Total PMP $) (Program Type)

Whereas the Radar Cost Model consists of the following area: Cost = F (Aperture, Power, Frequency), Schedule duration = F (Power, Radar Type), and Schedule Expenditures = F (Aperture, Frequency, Radar Type). In short, product life cycle cost created the above categories of cost drivers by identifying their sub-costs [124, 55]. Radar cost drivers can be divided into two types; SDC (System Definition Cost), and VC (validation cost), as shown in Table 9: System definition cost (SDC) and cost drivers.

Table 9: System Definition Cost (SDC) And Cost Drivers Source: (Dhillon, 2009)

Cost Drivers	Cost Breakdown Structure
System Definition Costs (SDC.)	Proposal preparation cost, bid and proposal evaluation cost, cost of negotiation, general and administrative cost, cost of each design review, cost of each technical review, cost of each program review, cost of each design review, cost of model preparation, cost of prototype fabrication, cost of prototype test and evaluation, cost of each design review, cost of each technical review, cost of each program review.
Validation Costs (VC.)	Engineering design and development cost, fabrication and manufacturing cost, validation hardware cost, software design cost. The radar cost model also includes cost and schedule duration functions based on factors such as power, radar type, aperture, and frequency. Validation costs (VC) can be divided into categories such as engineering design, manufacturing, logistics and support, quality improvement, post-design and development life cycle, transportation, test equipment, and training and equipment development.
Acquisition Costs (AC.)	Software and firmware – manufacturing-related cost, software and firmware depot-related cost, Initial training cost, vendor warranty cost, test equipment cost, radar system data and documentation cost, program management cost, general administration overhead cost. The literature review on the costing of the design of radar system remanufacturing highlights the importance of considering various factors and techniques in order to accurately estimate the costs associated with the production and remanufacturing of radar systems.. Overall, this literature review provides a comprehensive overview of the various factors and techniques that should be considered in the costing of the design of radar system remanufacturing.
The Operation, Maintenance and Support Costs (OMSC)	Operating personnel cost, electric power cost, communication facilities cost, occupying and housekeeping cost, consumable's cost, dedicated maintenance personnel cost, recurring spares cost, logistics cost, maintenance preventive and corrective cost, equipment rental, training cost and maintenance by contractor cost. There are several cost drivers to consider when estimating the cost of radar systems, including hardware and software costs, procurement costs, and obsolescence management. The procurement process is a critical cost driver, as companies in the UK and Europe rely on a competitive supply chain. Hardware costs are dominated by components, and transduction and computation are key parts of the radar system with different lifecycle characteristics. Software changes can be a significant source of cost overruns, and it is important to consider how payment is made for software changes.

It is important to note that cost estimation is a crucial process in predicting the total cost of a project, including labour, materials, and other elements. NASA has defined project (NASA, 2008) Life Cycle Cost Estimate (LCCEs) as "a full cost accounting of all resources necessary to design, develop, deploy, field, operate, maintain, and dispose of systems over its lifetime." To accurately estimate costs, it is essential to understand the project being estimated, develop a cost methodology and approach, and conduct, present, and maintain the cost estimate. The cost drivers of radar systems can be divided into two categories: hardware and software. Hardware accounts for a small portion of the non-recurring engineering cost, while software changes account for much of the cost over-run. Obsolescence management is crucial for high-value parts, and it is important to proactively mitigate obsolescence issues to minimize their impact. Radar cost drivers can be further divided into system definition costs, validation costs, acquisition costs, and operation, maintenance, and support costs. It is important to consider the cost breakdown structure of each of these equations in order to accurately estimate the costs of a radar system.

Life Cycle Cost

In this literature review, the costing of design for radar system remanufacturing is discussed, including the critical steps and trade-offs involved. Data collection is a major challenge in the trade-off process, as finding stakeholders' preferences and dealing with unknown factors can increase the complexity of the study. A decision-making technique, such as the analytical hierarchy process (AHP), can be used to make pairwise comparisons of decision-making elements and validate the effectiveness of quality and cost trade-offs. Obsolescence management is also critical for high-value parts, as proactive mitigation strategies can minimize the impact of obsolescence on the cost of the product.

The costing platform for radar systems integrates performance, scheduling, and cost to support cost estimating for the air force. The cost model estimates the development and production cost of radar systems based on performance, design, physical parameters, and sub-assemblies. Validation costs and acquisition costs are also important considerations, as well as operation, maintenance, and support costs. As identified by transmitter and receiver modules are key cost drivers for radar systems and discuss recent practices in radar technology, such as functional integration and the use of solid state technologies and printed circuit board technologies [125, 126]. Life cycle cost (LCC) is another important aspect to consider, as it can be divided into procurement costs, operation costs, and logistics costs. LCC cost drivers can also be divided into sub-cost drivers, such as research and development, production, and disposal. Future research should focus on incorporating "lifecycle thinking" into the design of maritime products for remanufacturing sustainability and compliance with codes of conduct.

Radar life cycle cost provide different costing model for calculating life cycle cost (LCC) of the radar system [124, 55, 56]. Could divided LCC into three types: procurement costs (28%), operation costs (12%), and logistic cost drivers (60%). Furthermore, the LCC cost drivers are divided into sub-cost drivers, shown in Figure 7: Life cycle cost drivers and sub cost drivers.

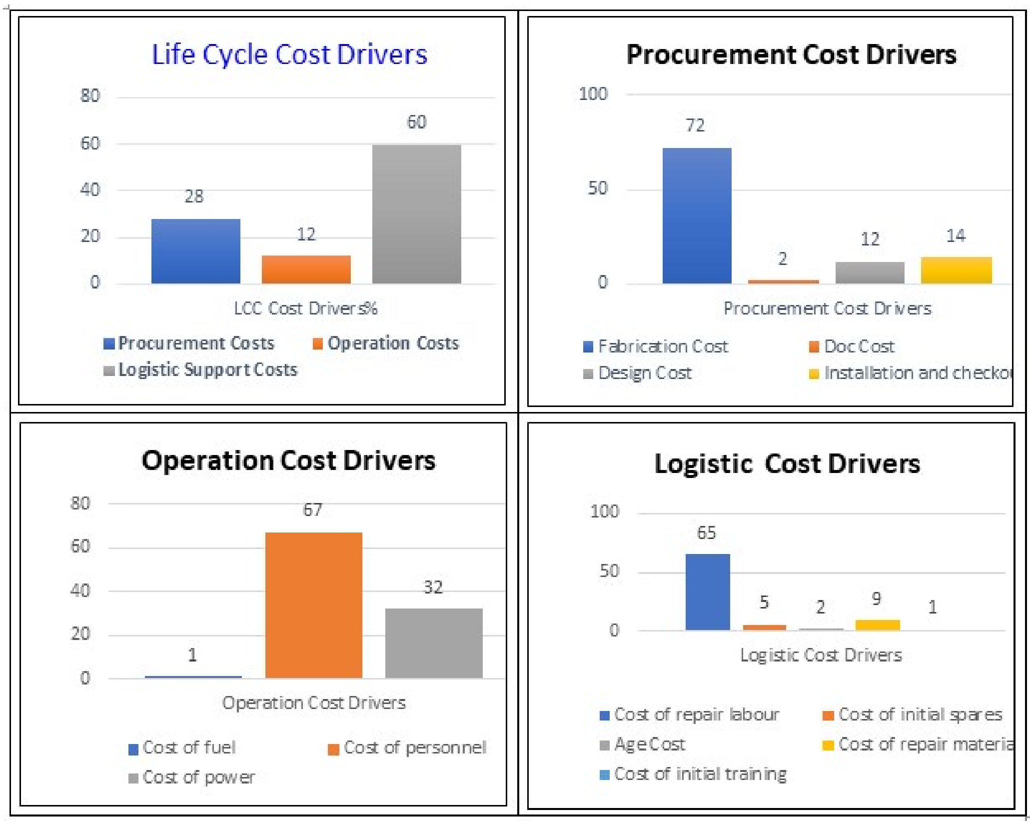

Figure 7: Life cycle cost and sub cost drivers

The Maintenance Cost of the Radar System

Life cycle costing created a cost estimation model for the maintenance of the radar systems and provided the following equation for the cost estimation equation [124, 75, 127]:

$$C_t = C_{mh}\, x\, H_y \text{ x } X/1000$$

Equation 1: MAINTENANCE of Radars

- C_t is the total radar maintenance cost.
- H_y is the number of navigating hours per year.
- X is the total number of years in operation
- C_{mh} is the maintenance cost per service time hour per unit. (1000 dollars (x103))

To calculate the Cmh, value, use the following equation in which $\beta 1$ and $\beta 2$ are constants: P_k = Peak power in kilowatts

$$\ln Cmh = \beta_1 + \beta_2 \ln P_k$$

Equation 2: Maintenance Cost Per Navigation Hour Per Unit

- Whereas $\beta 1$ = -2.086 and $\beta 2$ = 0.611 (Constants Values)

Only a few existing costing tools have elements of product lifecycle costing parts covering the product design changes, which are dissimilar lifecycle profiles impact of re-manufacturability enhancement product features on an initial redesign before remanufacturing. However, this costing platform would improve quality based on the requirements of the design to cost guidelines' "effectiveness and robustness". In addition, some tools have lifecycle thinking based on product design assembly and disassembly [128, 122, 129, 130].

The main objective of the validation process was to ensure that the company obtained the desired model for supporting cost and design improvements for the radar system remanufacturing, based on the quality improvements required for its lifecycle. However, a key challenge arises from the discrepancy between the level of analysis and the level of data available from the product design engineering system used in ECO (Engineering Change Order) databases [131-136]. This lack of required data can result in invalid conclusions and raises significant concerns about the final functionality of the tool [137-140].

The limitation of available data in this study necessitated a reliance on expert opinions, which ultimately proved beneficial for the maritime company as it gained valuable insights into the cost and value of data. As previously noted in this literature review, the integration of product-service elements into the costing model has been emphasized by several scholars. However, according to, further research is needed to determine the most effective way to combine these best practices into a comprehensive costing solution for maritime products partially address this need [141, 142,].

Identify Knowledge Gaps

Prior to this research, there was a significant lack of knowledge in the maritime industry regarding the costing of radar design, production, engineering techniques, and remanufacturing [143-147]. This comprehensive benchmarking study on costing industrial best practices was conducted to identify the current design to cost processes, cost trade-off techniques, and cost estimation methods that are necessary for companies to share and implement.

The practical application of the design costing tool involves the development of a parametric costing model for radar systems, which includes training on the use of the tool and its implementation in current processes, as well as the identification of data collection points for product lifecycle cost estimation and quality improvements. In summary, the software tool was designed to facilitate the application of cost engineering concepts under analysis and to identify cost drivers in order to make improvements to the product design throughout its lifecycle. This costing model enables users to utilize cost trade-off tools and is also useful in developing quality standards for remanufactured products, with the aim of improving quality at the end of the lifecycle.

As this literature review has revealed, previous research on remanufacturing has largely focused on general remanufacturing rather than specifically on radar and navigation systems in the maritime sector. This indicates that current knowledge, tools, methods, and platforms may not be sufficient to address the needs of the maritime industry. To address this gap, the tool used in this study incorporated critical cost engineering methodologies, including the use of historical data and expert judgment, and utilized the corrective action board (CAB) review process to provide solutions. It is important to note that not all cost estimating methods are suitable for every stage of product development, and each methodology requires different expertise from the end-users. For instance, experts should utilize analogy-based estimation to identify cost drivers in product development.

As a result, the tool's cost estimation methods were complex in their inclusion of all product ranges and types due to the need for historical data and the time required for review by the corrective action board. Despite the availability of many new tools and costing templates based on recent research, this literature review has shown that only a few products are currently used for remanufacturing, and even fewer are designed specifically for remanufacturing as discussed in [19, 148, 141].

To address this gap, Johansson conducted a comprehensive literature review to identify the critical success factors for remanufacturing based on product management, development, competence, and motivation [119, 143, 81]. There has been extensive literature on the benefits of designing certain products for remanufacturing, with a particular focus on costing considerations. The use of a design for costing template can improve the end-of-life design of products for remanufacturing, increasing efficiency and allowing more high-value products to be remanufactured, resulting in cost savings and new revenue for organizations while also having a positive environmental impact. However, there is a lack of empirical evidence in the literature demonstrating the benefits of implementing this approach in the maritime sector for vessels. Therefore, further case studies are needed to validate the cost-effectiveness of the costing of design template through the redesign of maritime products for remanufacturing in the vessels and companies.

Conclusion

This literature review has presented a review of the design costing platform for remanufacturing research, drawing on journal and conference papers published on the topic over the past 25 years. Through this review and a general understanding of best practices, a costing platform for the maritime sector has been developed, incorporating findings on the costing trends and techniques used in other sectors and incorporating the best frameworks and costing methodologies as well as standard agreements and issues identified by leading remanufacturing academics. The proposed solution for the maritime sector involves redesigning products and conducting sea trials as a validation process to assess the effectiveness of the solution before implementing it with improved quality based on design or production process changes.

This literature review has identified areas for future investigation. Prior to this research, there was a lack of knowledge on cost engineering techniques as noted by and the use of remanufacturing quality management standards in organizations [47, 149-151,]. Therefore, this comprehensive benchmarking study on industrial best practices was conducted to identify the current design to cost processes, cost trade-off techniques, and cost estimation methods used in maritime companies. The radar system costing based on design requirements is depicted in Figure 8: Costing of design platform, which can be used as a reference for other sectors and applications after taking the necessary steps.

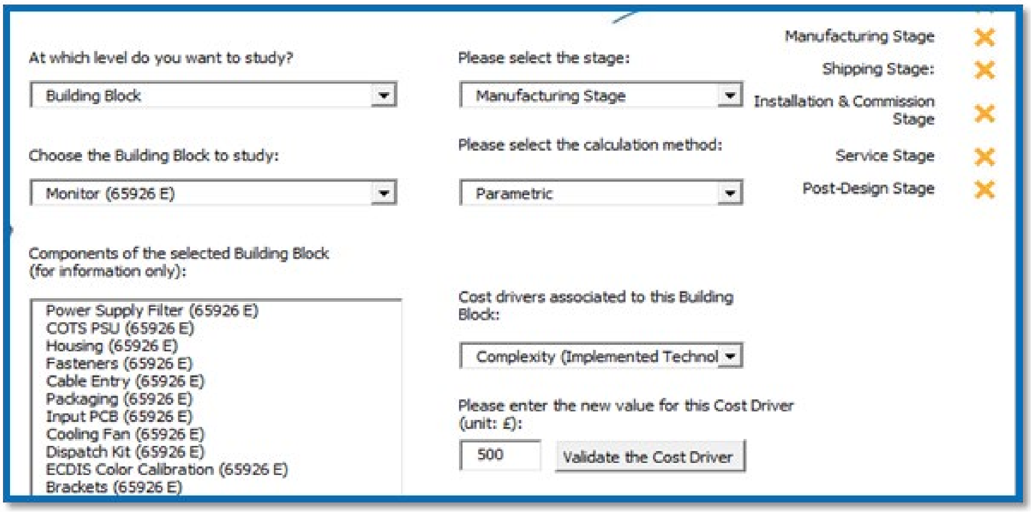

Figure 8: Costing of design platform

Due to supply chain issues, the cost of the radar system has increased by 5% for the parts prices in 2023, as shown in Table 10: Radar system costing analysis.

Table 10: Radar system costing analysis

Radar System Building Blocks	Costing of Parts in 2022	Cost of 2023 (5% increase)	Quantity used in the Configuration
Antenna (Six FT for X-Band)	7000	7350	
Antenna (12 FT for S-Band)	9000	9450	1
X-Band Turing Unit with TX/RX	7500	7875	1
X-Band Turing Unit without TX/RX	3500	3675	
S-Band Turning Unit with TX/RX	8500	8925	
S-Band Turning Unit without TX/RX	4000	4200	
Scanner control Panel	100	105	
Cable Installation Kit A	5000	5250	1
Cable Installation Kit B	8000	8400	
Monitor	4000	4200	1
Metal housing	500	525	1
Processor Units	2000	2100	1

I/O Control Unit	500	525	1
Control Panel	750	787.5	1
Interswitch	250	262.5	
Total	60600	63630	8

Many remanufactured products are the result of luck rather than intentional redesign efforts as noted by, which may explain the limited prevalence of remanufacturing in the maritime sector [49, 13]. If this issue persists, it is necessary to investigate the reasons why many maritime suppliers may not have fully realized their potential in terms of remanufacturing process efficiency due to a lack of technical understanding of the design requirements of maritime products. To address this, companies must develop remanufacturing-approved sub-suppliers for high-value radar systems and navigation products that can be remanufactured for multiple lifecycles in vessels and shipyards for new build ships.

During the benchmarking study phase, all radar system-related information was gathered and analysed in order to develop solutions for the company regarding recommendations for improvements and suggestions for suitable changes in processes and procedures (as discussed in [152-155, 141]. The main focus of this research was on the costing of design, as more than 40% of the industries and companies studied were using costing tools for life cycle costing of products [156-159, 95]. Therefore, it was concluded that the costing of design has become a significant issue (as noted by in the market, as organizations seek to gain a competitive advantage [160-162].

The author believes that it is particularly important for future work to recognize the need to redesign the product as the most crucial step in improving product quality and producing remanufactured products with improved quality, as demonstrated in the case studies of radar systems [116, 163, 73]. Additionally, it is essential to consider how to reduce warranty costs and redesign work to support product lifecycles in vessels and end-of-life for remanufacturing. This research has uncovered many untapped opportunities, as the costing platform is critical to business decision-making at all stages, contributing to a better understanding of remanufactured products in the maritime sector. It is important to conduct literature reviews and benchmark case studies of industry best practices, recommendations, and suggestions for organizations to make the following changes to the design to cost product improvements based on cost trade-off (CTO) techniques and cost estimation (CE) methods as presented in this paper. The cost engineering platform offers the following benefits for the organization:

➢ Developing design costing knowledge hubs and raising awareness of the importance of cost estimation processes to identify all direct and indirect cost drivers.
➢ Understanding cost estimation using prototypes of parametric analogy and detailed cost estimation models can assist in the decision-making process by demonstrating the visual impact of process or product design changes on cost.
The software tool equations used to create a parametric costing model serve as a decision-making platform with a trade-off background supported by an accurate and detailed understanding of cost drivers. This model guides end-users through a process to make an optimized decision, and the costing of product design process is aligned as discussed in with precise cost data management [164, 165]. In summary, as the tool becomes more complex, it will require more data inputs to maintain it. Additionally, design costing knowledge is not limited to the costing department but requires input from all relevant parties. Therefore, it is crucial to coordinate efforts to build the best radar costing model possible in order to obtain accurate and understandable cost estimates to improve design and production processes prior to remanufacturing and ensure the success of the product in the vessels, as shown in Figure 9: High-value products remanufacturing.

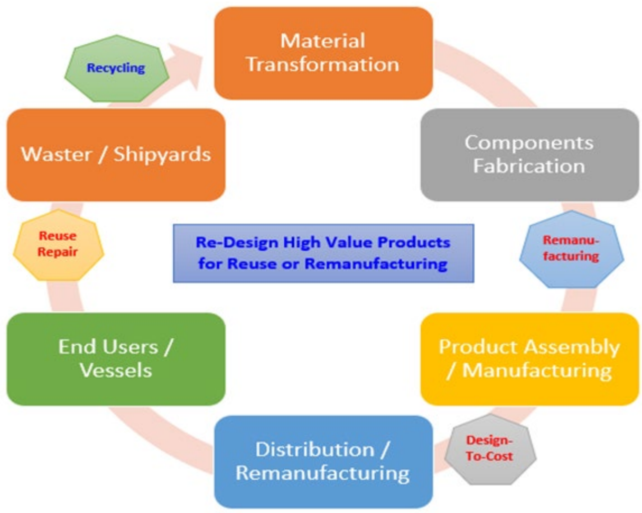

Figure 9: High value products remanufacturing

Organization often seek out new technologies and utilize lean Six Sigma as discussed in production techniques to enhance product design, production floors, manufacturing processes, and operational improvements [166, 167, 168]. Solutions are developed as noted by throughout the product's lifecycle to address issues that it may encounter, and the cost estimation (CE) process plays a crucial role in improving the design for remanufacturing based on customer demand [169-171, 142].

Cost estimation has become a key business driver in many industries, playing a vital role in all strategic decisions that may enable a company to remain competitive in this globalized era. The ability to estimate the cost of required design changes to the product's lifecycle, particularly for remanufacturing, can be a crucial business driver for end-users and customers in many industries [164, 172-174]. The main challenges in costing models are the lack of lifecycle quality data and issues which future research should address, as identified in this paper through the literature review based on current gaps in literature analysis. Essential recommendations for future research should include the need for improvements to maritime systems and radar design based on redesign and production process changes. Companies should share tools and methods with remanufacturers or critical customers to support remanufacturing activities with integrated quality in the design process from sub-suppliers and design houses for redesign improvements [175-196].

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Data Availability Statement

All data underlying the results are available as part of the article, and no additional source data are required.

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Conflict of Interest

The authors declare that they have no conflicts of interest concerning the publication of this research paper. All authors have contributed significantly to the development and execution of the study, and have reviewed and approved the final manuscript. The authors have no financial or personal relationships with any individuals or organizations that could potentially influence the research or its findings. This research was conducted ethically and without any outside influence.

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