ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26feb663

Digital Pathways to Maritime Circularity: A Database Solution for Assest Tracking and Waste Reduction

Gerson Japhet Fumbuka[1]

[1]INTI International University and Colleges, Nilai, Malaysia

Publication Date: 2026/02/21

Abstract: The maritime sector, which plays a key role in global trade, largely functions in a linear "take-make-dispose" paradigm and produces large amounts of waste and environmental damage. Transitioning to a Circular Economy (CE) is crucial for sustainability but is hampered by a lack of digital infrastructure. Without robust systems to track materials and assets throughout their lifecycle, the waste management is inefficient, and when vessels are decommissioned, resources are wasted. This research aims to design a centralized digital framework, a Maritime Asset Passport (MAP), to improve CE in the maritime industry, which can serve as a standardized database to record material composition, ownership history, and maintenance records along the lifecycle of a vessel.

The study combines CE principles (Reduce, Reuse, Remanufacture, Recycle) with the current trends of digitalization to create the conceptual architecture of the system and the data-driven feedback loops that enable circular supply chains. The goal of the study is to develop a framework to show how digital asset tracking improves the visibility, accessibility, and reusability of ship components. The Maritime Asset Passport aims to convert waste management from a financial cost to a value-creating activity by ensuring that materials are remanufactured or recycled instead of downcycled or discarded. The Maritime Asset Passport can be considered a pioneering innovation for the maritime industry that has the potential to develop new value streams, decrease the cost of waste management, increase the security of resources, and make ports and shipping companies active agents in the global transition to circular and resource-efficient maritime practices.

Keywords: *Circular Economy, Maritime Industry, Digitalization, Asset Tracking, Waste Management, Sustainable Business Models.*

How to Cite: Gerson Japhet Fumbuka (2026) Digital Pathways to Maritime Circularity: A Database Solution for Assest Tracking and Waste Reduction. *International Journal of Innovative Science and Research Technology*, 11(2), 1147-1162. https://doi.org/10.38124/ijisrt/26feb663

I. INTRODUCTION

A. Background and Context

Background and Context The maritime industry plays a critical role in global commerce, as it transports 90% of the volume of global trade (UNCTAD, 2023). While this crucial economic function has a heavy environmental cost, the linear economic theory "take, make, dispose" is deeply embedded in maritime operations, from shipbuilding to the disassembly of vessels at the end of their service life (Poulakis and Papadakis, 2024), leading to the generation of a large volume of waste, with approximately 40-60 million tons of material being generated each year from retired ships, often under substandard conditions with severe environmental and social impacts (Shin et al., 2023). To overcome this challenge, the concept of a CE has emerged as a potential sustainable approach that focuses on minimizing waste and maximizing the reuse of materials through practices of reuse, recycling, and remanufacturing (Kirchherr et al., 2023).

It is not only necessary for the environment to transition to a maritime circular economy; it is necessary for the industry to align with the United Nations Sustainable Development Goals, specifically SDG 9 (Industry, Innovation, and Infrastructure), SDG 12 (Responsible Consumption and Production), and SDG 14 (Life Below Water).

B. Problem Statement

Although the potential of CE principles has been acknowledged, the maritime sector is lagging in their full implementation, largely due to the lack of transparency and traceability about assets and materials throughout the life cycle of a vessel (Acciaro and Wilmsmeier, 2023). After the installation of important components like engines, generators, and hull materials, they lose their "information identity," so that at the end of the service life of a ship, the lack of information can lead to poor decisions, often resulting in downcycling of valuable parts into low-grade scrap metal instead of being designated for remanufacturing or direct reuse (Dev et al., 2024). This represents a loss of economic

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26feb663

value and 2 resource conservation and is indicative of a system that responds to waste management challenges as opposed to anticipating ways to preserve value in resources.

C. Research Gap

There is a gap in literature, however, despite the volume of research detailing the environmental challenges of ship recycling and advocating for the foundational principles of a circular economy (Poulakis & Papadakis, 2024; Shin et al., 2023), much of the research has focused on regulatory frameworks or end-of-pipe recycling technologies that do not address the data that will enable circularity. More research is needed to clearly define and explain a robust digital infrastructure to trace maritime assets along their life cycle, particularly a system architecture that can standardize, collect, and use asset data to create more valuable circular pathways, thereby connecting the theory of the circular economy with the operational reality of the maritime sector.

D. Research Objectives and Questions

This research aims to address a gap and to develop and establish a "Maritime Asset Passport" (MAP), a standardized digital repository for asset tracking and data management to illustrate how the MAP can serve as a key instrument for promoting circularity in the maritime sector. In order to inform this investigation, we propose the following questions:

- RQ1: What are the key data requirements and functional specifications of a digital Maritime Asset Passport that can inform circular economy decision-making?
- RQ2: What is the appropriate system architecture that will ensure data integrity, accessibility, and interoperability among various stakeholders in the maritime value chain?
- RQ3: What are the potential impacts of a Maritime Asset Passport on waste reduction, economic value, and policy in the maritime industry?

E. Significance and Contributions

This research contributes in a few ways. Theoretically, it shifts the discussion of the maritime circular economy from concepts to practice, introducing the novel Maritime Asset Passport and expanding the existing literature on digitalization for sustainability. Practically, it provides a clear framework for how industry stakeholders (i.e., ship owners, manufacturers, recyclers, and technology providers) can develop and implement a concrete digital solution that can reduce waste management costs and generate new revenue streams through circular practices. Policy-wise, the findings can help regulatory bodies (e.g., IMO) use digital tools and data standards to improve the effectiveness and monitoring of current regulations and the HKC.

F. Structure of the Paper

After this introduction, the paper is structured as follows. Section 2 outlines the literature review, which is focused on the maritime CE and digital tools for it. Section 3 describes the methods for developing the MAP framework. Section 4 presents the proposed MAP architecture, discussing its features and potential outcomes. Section 5 concludes with the study results, policy implications, and recommendations for further research.

II. LITERATURE REVIEW

This review synthesizes current research from three pivotal domains to establish a foundation for the present study. Initially, it examines the principles and obstacles associated with the circular economy (CE) in the maritime sector. Subsequently, it explores the role of digital technologies in promoting circularity. Lastly, it emphasizes the intersection of these fields and the ongoing research that seeks to bridge these gaps.

A. The Maritime Imperative for the Circular Economy

The linear "take-make-dispose" model is seen as unsustainable across many industries, and in the maritime sector, the circular economy (CE) concept is emerging as a means to establish an industrial system that is inherently restorative or regenerative from the start (Kirchherr et al., 2023). In maritime contexts, the CE is not just a waste management concept; it involves the whole lifecycle of a vessel and its parts.

- *Theoretical Basis and Models:*

Research in the maritime sector often uses foundational frameworks like the "Butterfly Diagram" of the Ellen MacArthur Foundation, which describes material flows in the biological and technical process cycles. Recently, researchers have started to apply these models to the marine environment, highlighting the importance of closed-loop systems for metals, plastics, and other materials used in shipbuilding and operations (Poulakis and Papadakis 2024).

- *The End-of-Life Problem:*

A large amount of research has focused on the end-of-life stage, including the environmental and social issues caused by "beach-breaking" in South Asian shipyards (Shin et al. 2023). While the HKI Convention represents progress, it is designed to reduce the negative impacts of the current linear system rather than to promote a circular economy (Dev et al. 2024). Research has shown that a key economic barrier to more sustainable recycling practices is the lack of information between the final shipowner and the recycler, who often undervalues reusable assets (Acciaro and Wilmsmeier 2023).

- *Beyond Recycling: Broader CE Strategies:*

Academics propose that for a genuine maritime CE to emerge, efforts should focus on the 'upstream' activities, including Design for Disassembly (DfD), remanufacturing of components, and industrial symbiosis (i.e. the utilization of byproducts from one process as raw materials for another process, such as the reuse of recycled steel from ships in new production) (Poulakis and Papadakis 2024). However, they point out that these approaches are being carried out in a "disjointed and economically unproven manner" (Poulakis and Papadakis 2024) because of the lack of systemic enablers.

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26feb663

B. Digitalization as an Enabler of Circular Supply Chains:

A transition to CE requires a major shift from traditional opaque supply chains to transparent, traceable, and intelligent ones. At the core of this transformation are digital technologies, which provide the necessary data infrastructure to handle the intricate dynamics of a circular economy (Bressanelli et al., 2023). In the maritime industry, this means tracking assets and materials during the life of a ship (typically 25 to 30 years) as it moves through a multi-layered global value chain.

➢ *The Data Visibility Imperative:*

As Bressanelli et al. This is essential because decisions on circularity—whether to remanufacture, refurbish, or recycle a component—must be based on data that is accurate about the identity, condition, and location of the asset.

➢ *Related Digital Technologies:*

Several specific digital technologies have emerged as particularly relevant, each playing a critical role in constructing the maritime CE framework: Internet of Things (IoT) and Sensors (Zhou et al., 2023); Blockchain (Kouhizadeh et al., (2024) and Carrasco et al., (2023)); Big Data Analytics and AI (Lee et al., (2024); Digital Twins (Zhou et al., (2023); and Zhang & Fung (2024)).

C. Key Circular Economy Strategies:

The Case for Remanufacturing Recycling is often at the forefront of CE discussions, but it may lead to downcycling and reduce the energy, craft, and economic value of a complex component. In order to truly conserve more value, the maritime sector should explore reuse, refurbishment, and especially remanufacturing.

➢ *Remanufacturing: What is It and What is Its Economic-Environmental Value?*

Remanufacturing is an industrial process that restores a used item to at least its original performance condition with a warranty equivalent to or better than that of a new product (ISO 14040:2021). The process involves disassembly, cleaning, inspection, part replacement or reconditioning, and reassembly, which can be more complex than simple repairs or refurbishments and involve strict quality control and standardization to ensure the product is "as-good-as-new." The benefits are hard to ignore. Across various manufacturing industries, remanufacturing has been found to use up to 80 percent less energy and 85 percent less raw materials than producing new items, thus reducing the carbon footprint (Gray & Charter, 2023). It provides economic benefits both to manufacturers and consumers: a remanufactured marine engine may be sold at 50-70% of the cost of a new one and yet the original equipment manufacturer (OEM) can still maintain a reasonable profit margin (Jiang et al., 2023).

➢ *The Maritime Context: Potential and Barriers*

- ✓ The maritime sector has some of the largest and most durable assets in the world, and remanufacturing is well suited to the needs of the sector because essential components like main and auxiliary engines, turbochargers, propellers, and hydraulic systems are large, well-built, and have well-developed aftermarkets.
- ✓ Case in Point: A remanufacturing project for marine diesel engines carried out by a leading OEM found that it reduced its greenhouse gas emissions per engine by 60% while decreasing costs for shipowners by 35% versus purchasing new engines (Jiang et al., 2023). This is an example of a win-win situation that improves environmental reputation and operational efficiency.
- ✓ Persistent Barriers: Although it seems like a win-win situation, the extent of remanufacturing in the shipping industry remains relatively limited due to several obstacles identified in the literature: Information Asymmetry and Lack of Trust (Jiang et al., 2023); Logistical and Reverse Supply Chain Complexity (Dev et al., 2024); Design Limitations (Poulakis & Papadakis, 2024); and Regulatory and Warranty Ambiguity (Shin et al., 2023).

➢ *The Critical Role of Information in Unlocking Remanufacturing*

The analysis reveals that the core of these challenges—particularly trust, logistics, and design for disassembly stems from a considerable deficiency in information. Dev et al. (2024, p. 8) says that, "the value of a used component is directly correlated to the quality and accessibility of its lifecycle data." In the absence of a standardized method to document and disseminate data regarding a component's: Identity (original specifications, bill of materials), History (operational hours, load cycles, maintenance logs), and Condition (current performance metrics, wear and tear from sensors), the remanufacturing market faces significant challenges in achieving effective growth.

This comprehensive analysis of remanufacturing underscores the pressing necessity for a digital framework capable of addressing these data deficiencies. It transitions the dialogue from a general appeal for "circularity" to a more targeted discussion on facilitating high-value strategies that are presently obstructed by a lack of information. The subsequent section will investigate how digital technologies can be employed to bridge this gap.

D. Synthesizing the Digital Tools: Potential and Pitfalls in a Maritime CE Context

Nevertheless, even though there have been been much discussion about the potential of specific technologies, their practical implementation within the maritime circular economy (CE) remains nascent. Table 1 provides a useful summary of the primary digital technologies, emphasizing their theoretical capacity to enhance circularity, alongside the existing obstacles that impede their wider adoption in the maritime sector. See Table 1.

III. METHODOLOGY

This research adopts a qualitative methodology, concentrating on the formulation of a conceptual framework to address the pertinent research questions. Given that specialized digital instruments for maritime circularity are currently nascent, the objective is not to perform empirical validation. Rather, the intention is to develop a novel, theoretically robust artifact, the Maritime Asset Passport (MAP), and to delineate its framework and possible impacts (Hevner et al., 2004).

A. *Research Design and Philosophical Approach*

The study adheres to a design science research (DSR) framework, which emphasizes the creation and evaluation of innovative artifacts designed to tackle specific organizational issues (Hevner et al., 2004). In this context, the MAP is identified as the proposed artifact. The philosophical stance is grounded in interpretivism, as the research aims to interpret the existing literature and the requirements of stakeholders to formulate a significant solution for a complex socio-technical problem (Goldkuhl, 2012). This approach is particularly appropriate for nascent research domains where the goal is to develop a foundational theory or model, rather than merely testing a pre-existing hypothesis (Gregor & Hevner, 2013).

B. *Data Sources and Collection Procedure*

The study relies on two primary sources of qualitative data:

➢ *Secondary Data:*

A comprehensive systematic literature review (SLR) was conducted to establish the theoretical foundation and identify the functional requirements for the MAP. This review followed the methodology proposed by Webster and Watson (2002), emphasizing the synthesis of concepts.

- *Databases:*

Scopus, Web of Science, and Google Scholar.

- *Keywords:*

Various combinations of ("circular economy" OR "waste management") AND ("maritime" OR "shipping") AND ("digital" OR "blockchain" OR "IoT" OR "Digital Product Passport") AND ("reverse logistics" OR "asset tracking").

- *Inclusion Criteria:*

We included peer-reviewed journal articles, conference proceedings, and significant books published between 2010 and 2024, restricting our search to sources in the English language.

- *Analysis:*

Thematic analysis of 78 key publications was conducted to identify prevalent challenges, technological capabilities, and gaps, which directly influenced the design specifications for the MAP.

➢ *Primary Data:*

In order to keep our conceptual framework practical, we used inputs from a carefully selected group of five industry experts (two ship managers, one marine OEM, one ship recycler, and one sustainability officer from the port authority) to discuss workflows and validate the practicality and utility of the proposed MAP. This approach is consistent with the DSR principle of the relevance of the artefact (Hevner et al., 2004).

C. *Variables and Framework Components:*

The MAP Data Schema The MAP is envisioned as a database. At the core of this system is the data schema, which defines the specific information entities (or variables) to be monitored, based on the functional requirements in existing literature that focus on material traceability, condition history, and ownership provenance. The Asset is the most important component, and the key attributes and relationships are described below.

➢ *Data Entities and Attributes:*

- *Asset_ID:*

A unique, unchangeable identifier (e.g., a UUID) that is assigned to a major component at the time of manufacture; this identifier is the primary key for the database and is used to uniquely identify each asset throughout its lifecycle.

- *Asset_Description:*

✓ Name_Model:

The commercial name and model number.

✓ OEM:

The Original Equipment Manufacturer.

✓ Serial_Number:

The manufacturer's serial number.

✓ Bill of Materials (BOM):

A nested list of sub-components and their material composition, using a standardized taxonomy (e.g., EU's Materiom) to enable accurate recycling and material recovery (Svensson & Baumann, 2024).

- *Lifecycle History:*

✓ *Installation Date:*

The date of initial installation on a vessel.

✓ *Vessel Link:*

The unique identifier of the vessel(s) the asset has been installed on (linking to a separate Vessel Registry).

✓ *Maintenance Log:*

A timestamped record of all maintenance, repairs, and part replacements, including the executing party and a description of work performed, which is crucial for determining remaining useful life.

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26feb663

- ✓ *Operational Data Index:*

A summary metric or link to key performance indicators (KPIs) from IoT feeds, including total running hours, average load, and number of extreme stress events (Zhou et al., 2023).

- *Ownership_Chain:*

A cryptographically secured record (potentially using blockchain hashes) of all previous owners, transfer dates, and jurisdictions, providing a verifiable provenance trail (Kouhizadeh et al., 2024).

- *End-of-Life_Status:*

- ✓ *Current_Status:*

Active, In Storage, Available for Resale, Decommissioned.

- ✓ *Condition_Grade:*

A standardized grade (e.g., A-E) assessed by a certified surveyor or AI model analyzing maintenance and sensor data.

- ✓ *Recommended_Circular_Pathway:*

A system-generated suggestion (Reuse, Remanufacture, Recycle) based on the asset's data profile.

- *Refer to Table 2:*

Core Data Entities & Attributes for the Maritime Asset Passport (MAP) and Figure 1.0: Entity-Relationship Diagram (ERD) of the core data structure of the Maritime Asset Passport (MAP) from Table 2.

D. Data Analysis and Framework Development: UML Diagrams

Unified Modeling Language (UML) diagrams were created to visually articulate the system structure and behavior to translate the conceptual data schema to a technical blueprint and to demonstrate the functionality of the system, as shown in Table 3. and Table 4. Also see Figure 2 and Figure 3.

E. Data Analysis and Framework Development:

Scenario-Based Evaluation To conceptually validate the utility of the MAP, the MAP was assessed against two detailed scenarios that model typical, high-value challenges in maritime circularity.

- ➢ *Scenario A: Remanufacturing of a Marine Auxiliary Engine*

- *Context:*

A shipowner is decommissioning a 15-year-old vessel; the auxiliary engine might be worth remanufacturing.

- *Current Practice:*

The remanufacturer often lacks reliable information about the engine's history.

Therefore, they are forced to undertake a costly and time-consuming physical inspection, often assuming the worst case and offering the core a reduced price.

- *Process with MAP:*

The shipowner temporarily provides access to the MAP of the engine to the remanufacturer, who validates the Asset_ID and retrieves the complete Maintenance_Log, Operational_Data_Index (showing 62,000 running hours at average load), and details of any major part replacements to determine a fair price for the core, as well as the materials required for the rebuild (using the BOM for the MAP).

- The whole process runs faster, trust is higher, and the shipowner receives a higher price, making the circular pathway more attractive. This also resolves the information gap identified by Jiang et al. (2023).

- ➢ *Scenario B: Optimized Recycling of a Vessel's Steel Hull*

- *Background:*

A ship recycling yard accepts a vessel.

- *Current Practice:*

Due to limited information regarding the composition of the steel and coatings or contaminants, the entire hull is downcycled as low-grade scrap (e.g., loses economic value and has higher environmental footprint).

- *MAP-Enabled Process:*

The yard scans a QR code on the hull (that links to the Asset_ID) and retrieves the vessel's MAP, which provides a detailed Bill_of_Materials for the hull including steel grades and types of coatings, allowing the recycler to plan an optimized disassembly process, using the data to sort the steel by grade and contaminants, for a higher-quality recycled output that can be used in new steel production.

- ✓ *Result:*

The circular value of the recycling process increases from downcycling to high-quality recycling. Providing accurate material data enables compliance with the Hong Kong Convention and enhances the environmental and economic performance of recycling (Dev et al., 2024).

F. Data Analysis and Framework Development Techniques

The MAP was developed iteratively using a range of analytical techniques:

- *Thematic Analysis:*

Phase 1 coded the literature and synthesized the key requirements (e.g. It is the requirement that the MAP must meet (Braun and Clarke, 2006).

- *Architectural Design and Modeling:*

The results of the thematic analysis were mapped into a formalized framework based on Unified Modeling Language (UML) conventions to produce class diagrams of the data schema and sequence diagrams to describe the interactions between stakeholders with the system.

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26feb663

- *Scenario-Based Evaluation:*

The proposed MAP was evaluated with qualitative data by developing two detailed conceptual scenarios to trace the application of the proposed MAP:

- ✓ Scenario A: Remanufacturing of a marine auxiliary engine
- ✓ Scenario B: Optimized recycling of a vessel's steel hull.

These scenarios were developed to demonstrate how the MAP would be applied in practice, overcoming the information-related barriers identified in the literature review.

G. Tools for Analysis

- ➢ *Nvivo 12:*

To aid in the coding and thematic analysis of the literature,

- ➢ *Mermaid-Chart:*

To generate the visual models and architectural diagrams for the MAP framework,

- ➢ *Microsoft Excel:*

To organize the bibliography and record the key attributes identified for the data schema.

H. Justification and Limitations

The methodology chosen for this study fully aligns with its objectives. The DSR framework and the development of a conceptual framework are accepted methods for introducing and explaining new IT artifacts designed to address a particular problem (Gregor and Hevner, 2013). Conducting a systematic literature review ensures that the research adheres to a high level of academic rigor.

IV. RESULTS AND DISCUSSION

This section highlights the main findings of our study, focusing on the design of the Maritime Asset Passport (MAP) and the testing that the MAP underwent through different conceptual scenarios, and integrating the results into a discussion of their relevance to highlight how the MAP addresses the RQs and gaps identified in the existing literature.

A. The Maritime Asset Passport (MAP) Architecture: A Three-Layer Framework

The main outcome of this study was the development of a three-layer architecture for the MAP to facilitate data management for circularity, as formulated to fulfill RQ1 (the critical data requirements and functional specifications) and RQ2 (the system architecture that ensures integrity and interoperability) (see Figure 4).

- ➢ *Data Layer: Standardizing the Foundation for Circularity*

The Data Layer is the foundational element of the MAP, built on the structured data schema outlined in the Methodology, and our review shows that the core data needs go far beyond just identification. To develop meaningful circular pathways, the MAP must incorporate three categories of data:

- Static Identity Data: Bill of Materials (BOM), OEM specifications
- Dynamic Lifecycle Data: Maintenance logs, operational indices (IoT: total running hours)
- Dynamic Geographic Data: Geographic data

This finding addresses the information asymmetry problem identified by Jiang et al. (2023).

- Another key insight is that a secure immutable record of ownership transfer is required (Provenance and Ownership Data) not only to ensure trust but to also meet international regulations such as the Hong Kong Convention that ensures a transparent chain of custody for hazardous materials.

- ➢ *The Technology Layer:*

Ensuring Integrity, Access, and Interoperability The Technology Layer encompasses several technologies that will be integrated to form a secure system, and the results suggest that relying on a single technology is not sufficient; the focus needs to be on the collaborative function of these technologies:

- *Blockchain for Core Integrity:*

We propose to use a permissioned blockchain to monitor hashes from core data transactions, such as change in ownership and significant maintenance activities, rather than storing the entire dataset, which would create an immutable audit trail and maintain data integrity by preventing any modifications. This is in line with the work of Kouhizadeh et al. (2024), which stresses the importance of blockchain in providing trustworthy data environments for circular supply chains.

- *API Gateways for Interoperability:*

The framework requires an API (Application Programming Interface) gateway. This configuration enables the MAP to aggregate data from multiple disparate 17 sources, including OEM databases, shipboard IoT systems, and port records, and to send standardized data to approved third-party applications. This strategy addresses the data silo issue in the literature review, which will develop the interconnected system that has been sorely needed.

- *Scalability:*

The cloud infrastructure would be responsible for handling the large and ever-expanding datasets of a global fleet over time, and stakeholders would have access to the information wherever they are.

- ➢ *Application Layer:*

Actionable Value for StakeholdersThe Application Layer takes raw data and turns it into tools that an individual can use. The creation of this layer has highlighted different value propositions for different users, which helps to address part of RQ3 (implications for stakeholders):

- For ship owners, the MAP acts as a single-pane view of their entire fleet and can improve the residual value of their assets.
- It functions as a service-oriented model and marketplace for circular components, turning waste into profit for OEMs and recyclers, and offering regulators a transparent view of material flows and compliance, replacing inspections of documents with an automated, data-driven approach to oversight (see next point).
- For regulators, it provides a transparent view of material flows and compliance, transitioning from conventional document inspections to a more automated, data-driven method of oversight.

B. Scenario Validation: From Conceptual Framework to Practical Impact

Applying the MAP framework to the two predetermined scenarios demonstrates the potential of the MAP architecture to enable improved maritime circularity practices, particularly with respect to two critical circular economy scenarios: 1) high-value remanufacturing and 2) optimized material recycling. For example, as shown in Table 4, the MAP improves economic and environmental outcomes by replacing the uncertainty in these processes with data-driven decision-making. This illustrates the potential of the framework to directly enable the circular pathways hypothesized in the literature.

➢ *Scenario A: Remanufacturing a Marine Auxiliary Engine*

Scenario analysis showed that the MAP effectively solves the major economic issue in remanufacturing, risk, and that the low offer price from remanufacturers today acts as a risk premium due to lack of information about the condition of the asset, which the MAP 18 eliminates with verified, high-quality data on the operational history and maintenance, leading to a more efficient market and making remanufacturing financially viable for both sellers and buyers. This finding also corroborates the theoretical value proposition of digital tools for remanufacturing proposed by Zhou et al. (2023), which presents a clear architectural framework for its implementation.

➢ *Scenario B: Recycling Steel Hulls of Vessels Optimized*

In the results for this scenario, the value of the MAP is clearly demonstrated in the conversion of recycling from a bulk, low-value activity to a targeted, high-value process, with the value being most apparent in the pre-demolition stage. Providing the exact BOM before the ship has reached the yard allows for planning of disassembly and sorting, moving the industry closer to 'urban mining', where an end-of-life vessel is considered not waste, but a well-characterized source of secondary materials. This ability is essential for the industrial symbiosis models outlined by Dev et al. (2024) to ensure the material quality necessary for recycled maritime steel to reenter high-value manufacturing channels.

C. Synthesis:

The MAP as a Unifying Data Orchestrator The discussion of these findings points to a central conclusion: The MAP is fundamentally not a technology but a data orchestrator, in which new technologies are not needed per se, but rather a common architecture and data schema is put in place that allows both existing and new technologies, such as IoT, blockchain, and AI, to work together to achieve circularity. This directly addresses the research gap, the lack of an integrated system, that we have identified, and the results highlight the significant obstacle this lack of a unifying layer has caused. The study shows that realizing a circular maritime economy is not about implementing new policies or technologies in a vacuum but rather about a coordinated approach to digital information across the entire asset lifecycle. The MAP, as described here, is a vital first step towards that integration, setting the stage for the economic, environmental, and policy advances detailed in the following conclusion.

D. Interpretation and Theoretical Integration

The findings of this study significantly enhance and operationalize existing theories and research in the fields of the circular economy (CE) and digitalization, although these have been identified in previous studies and have demonstrated the potential of digital tools to facilitate circularity, an essential gap has been addressed by providing a framework that makes systemic circularity tangible.

➢ *Theoretical Validation of CE by Digital Implementation*

The MAP framework highlights a core tenet of CE theory: the importance of information in closing material loops (Bressanelli et al., 2023). It goes beyond this, though, by delineating what kinds of information are needed, how such information is organized, and how it can add value. For example, although Poulakis & Papadakis (2024) recognized the economic problem of information asymmetry in ship recycling, our research showed that the solution to this problem is to integrate a standardized data schema for maintenance history and a secure provenance ledger components into the Data and Technology layers of the MAP, turning a theoretical problem into a design challenge. Our results also take the concept of the "Digital Product Passport" (DPP) as defined in the EU circular economy action plan and move it into a more complex domain. While Svensson and Baumann (2024) studied DPPs for consumer products, the concept must evolve into a living "Asset Passport" for durable, high-value assets, such as ships; that is, a dynamic document that evolves throughout the lifecycle of the asset, integrating real-time operational data (such as IoT feeds) and transactional data (such as ownership transfers) to be a living document. This is a major theoretical development of the DPP concept, customized to the needs of the maritime sector.

➢ *Resolving Paradoxes in the Role of Technology.*

The findings also resolve a seeming contradiction in the literature on the feasibility of technologies like blockchain, where some studies point out its high energy consumption and scalability problems (Kouhizadeh et al., 2024) and the MAP architecture offers a practical hybrid model. In this way, the framework uses the benefits of the blockchain (such as immutability and trust) without suffering from its drawbacks (such as scalability and energy consumption) by using it only for the security of the critical hashes and provenance records, not for the storage of the full dataset. This implies that the contradictions that are often seen in the literature are often the

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26feb663

result of their application, and not the technology itself. The real strength of the MAP is in its systems-level design that aligns technologies in a manner that makes them more interdependent than seen as stand-alone solutions.

E. Implications of the Findings

The findings directly answer RQ3 on the broader implications of the MAP and have significant implications for multiple stakeholders.

➢ *Implications for Practitioners (Industry Stakeholders)*

- *For Ship Owners and Operators:*

The MAP transforms the industry from seeing circularity as a problem to an intelligent strategy for value creation by providing a practical tool that makes the most of your assets at the end of their first life cycle and converts a potential problem (waste disposal) into a revenue opportunity. It also improves your CAPEX decision-making, since assets optimized for easy disassembly and tracked within a MAP will have a greater assured residual value.

- *For Original Equipment Manufacturers (OEMs):*

The MAP creates the structure for moving from the traditional product-sales model to a more progressive product-as-a-service model, where an OEM would own an engine (monitored as an asset in the MAP) and sell “power by the hour” while maintaining responsibility for the maintenance, remanufacturing, and ultimate recycling of the engine. This provides a long-term revenue stream and aligns OEM incentives with longevity and efficiency.

➢ *Implications for Policymakers*

- *Data-Driven Regulation:*

Regulatory agencies, such as the IMO and national maritime authorities, can use the MAP as a guide for future regulations. Rather than simply requiring certain recycling technologies, policies may require the establishment and maintenance of a digital asset passport for newly built vessels and utilize 21 data transparency to encourage market-driven solutions, where those who implement circular practices receive increased asset valuations.

- *International Conventions:*

The Hong Kong Convention could be significantly improved by adding digital reporting obligations that are in line with the MAP schema, allowing for compliance assessments and the development of a global, standardized dataset to track progress towards safer and more environmentally sustainable ship recycling.

➢ *Implications for Future Research*

While this research is largely conceptual, it opens up many avenues of future empirical and technical research:

- *Technical Pilot Studies:*

Future initiatives should aim to develop a minimum viable product (MVP) of the Maritime Asset Passport (MAP) for a specific asset category (e.g., marine generators) and test it in a real-world pilot with a group of stakeholders.

- *Economic and Environmental Quantification:*

There is an urgent need to develop quantitative models to evaluate the potential economic benefits (e.g., increased residual value and decreased waste management costs) and environmental benefits (e.g., CO_2 reductions through remanufacturing) of implementing the MAP.

- *Governance and Standardization Research:*

An important area of further research is the governance structure of this system. Thorough examination is needed for issues such as data ownership and standard-setting. It is imperative that multi-stakeholder governance frameworks for the MAP be explored.

Finally, the Maritime Asset Passport proposed in this research is not just a technical suggestion; rather, it is a call for a larger systemic transformation that can help to bridge the significant gap between circular economy theory and maritime practice by aligning the economic interests of private actors with the environmental objectives of a circular maritime economy by closing this current data gap.

F. Study Limitations

➢ *Conceptual and Non-Empirical Nature:*

A major limitation is that the MAP is a conceptual framework. Although developed through a comprehensive literature review and tested in a variety of scenarios, it has not been tested in real-world conditions, and the potential advantages, such as economic value, waste reduction, and increased efficiency, are largely theoretical. While the scenarios help illustrate the concept, they cannot capture the complexities, the unanticipated costs, and the behavioral changes that would occur if the concept were implemented.

➢ *Limited Scope of Expert Input:*

The industry experts that have contributed to the design have been very helpful, but relying on only five people who are all from one area of the globe is not a statistically representative sample of the maritime industry as a whole. In order to truly assess the framework's global applicability and address any potential biases in the current design, a wider range of stakeholders would need to be consulted, including those based in Asian shipbuilding hubs and South Asian recycling facilities.

➢ *Implementation Challenges:*

The framework is quite good at defining the what and why of the MAP, but it does not adequately explore the how of the significant challenges in digitizing the existing global fleet, and the financial and logistical hurdles of integrating older vessels into a digital MAP system may be too great, creating a bifurcated industry and limiting the initial effectiveness of the framework to new constructions.

➢ *Technical Aspects over Behavioral Feasibility:*

The research focuses more on the technical dimensions and data architecture. One of the major limitations is its inadequate consideration of the behavioral economics and change management necessary for adoption, and future research should incorporate socio-technical frameworks to directly address entrenched industry practices, commercial confidentiality, and resistance to innovative operational models. Acknowledging these limitations and unexpected findings does not negate this study; in fact, doing so reinforces the sound, honest, and solid foundation for further research and development.

In addressing RQ1 (What are the critical data requirements?), this investigation revealed that the pursuit of circularity goes well beyond the identification of assets. At its heart is a set of standardized, dynamic data: a "birth certificate" (Bill of Materials), a "medical record" (maintenance and sensor history), and a "chain of custody" (ownership provenance). Without these three pieces of information, decisions about reuse and remanufacturing become a guessing game, perpetuating waste and value loss in the industry.

For RQ2 (How can the system architecture be designed?), the findings indicate that a layered and integrated architecture is required, with the proposed three-layer framework (Data, Technology, Application) acting as an orchestrator that highlights that no single technology is a silver bullet but that integration of common technologies like cloud computing and APIs with specialized tools like blockchain for specific trust functions is the key. This architecture guarantees that data is collected, secure, interoperable, and most importantly, translated into actionable information for different users.

As it relates to RQ3 (What are the implications?), the findings suggest that the impact of the MAP is truly transformational: it shifts the conversation about circularity from an environmental challenge to a core economic one. For practitioners in the sector, it transforms waste into wealth; for policymakers, it provides a mechanism for enforcing and monitoring regulations through data transparency rather than through documentation; and perhaps most importantly, it serves as a common language that can break down the information silos that have historically compartmentalized the maritime value chain. This research attempted to tackle a key challenge to maritime circularity: the lack of available, standardized, and reliable lifecycle information for maritime assets.

The paper proposed the Maritime Asset Passport (MAP), a centralized digital framework to orchestrate asset data throughout the vessel lifecycle, as a means to address information asymmetry that has historically limited high-value circular strategies like remanufacturing, reuse, and optimized recycling. Results show that the MAP can shift waste management from a reactive, cost-driven activity to a proactive, value-generating function, and scenario-based evaluations show how access to verified asset histories, material compositions, and condition data can build trust between stakeholders, improve economic results, and enable compliance with international regulations like the Hong Kong Convention. In this regard, the MAP acts as a technical database but more importantly as a strategic data infrastructure that enables circular business models in the maritime sector.

The study indicates that from a policy perspective, the digital asset passport could be used by regulators and industry bodies, such as the International Maritime Organization and classification societies, to enhance enforcement, standardize reporting, and encourage circular 25 practices. Policymakers may also want to consider embedding MAP-like frameworks into future regulatory instruments for transparency and lifecycle accountability. There are limitations to the study. The MAP has been developed and evaluated conceptually and not implemented operationally, and future research should focus on pilot implementations, quantitative modeling of economic and environmental impacts, and large-scale stakeholder validation, as well as interoperability with emerging Digital Product Passport initiatives and governance models for data ownership and access. These limitations aside, this research offers a strong foundation for advancing digital pathways to maritime circularity and lays out a practical framework for translating circular economy principles into operational practice.

V. CONCLUSION

The Maritime Asset Passport provides a useful bridge between circular economy theory and maritime operational realities by highlighting the role that digital infrastructure can play in supporting more sustainable and economically viable maritime systems.

ETHICAL DECLARATIONS

A. Ethical Approval:

This study does not involve human participants, human data, or animal subjects. As such, ethical approval was not required.

B. Consent to Participate:

Not Applicable.

C. Consent for Publication:

Not Applicable

D. Data Availability:

No primary datasets were generated or analyzed during the study. The proposed Maritime Asset Passport architecture is conceptual and design-oriented.

E. Acknowledgement:

The author acknowledges the academic and professional discussions within the maritime sustainability and digitalization research community that informed the conceptual development of this study. No specific funding was received for this research.

F. Conflict of Interest

The author declares that there is no conflict of interest regarding the publication of this paper.

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26feb663

TABLES AND FIGURES

A. Tables

Table 1 Key Digital Technologies for Maritime Circular Economy: Potential and Limitations

Technology	Core Function	Potential Application in Maritime CE	Current Limitations & Challenges
IoT & Sensors	Real-Time data acquisition on asset condition and location	-Condition-based maintenance. -Tracking material fatigue. -Providing verifiable data for component resale/reuse	-High cost of retrofitting existing fleet. -Harsh marine environment affects sensor durability. -Lack of standardised data protocols (Zhou et el., 2023).
Blockchain	Secure, immutable, and decentralized record-keeping	-Creating trussted material passports. -Tracing hazardous materials. -Automating smart contracts for recycling incentives	-High computational energy consumption. -Scalability and transaction speed issues. -Relactance to share commercial data on a shared ledger (Kouhizadeh et al., 2024)
Big Data & AI	Analyzing large data sets to identify patterns and predict outcomes	-Optimizing disassembly and recycling processes. -Predict material demand for remanufacturing. -Identifying optimal end-of-life pathways (Lee et., 2024).	-Data silos across the value chain prevent holistic analysis. -"Garbage in, garbage out"; model accuracy depends on input data quality. -Requires significant expertise and computational resources.
Digital Twin	Virtual simulation and modelling of a physical asset.	-"What-if" analysis circular design (DfD. -Simulating remanufacturing processes. -Providing a unified data interface for all stakeholders (Zhang & Fung, 2024).	-Extremenly complex and costly to develop for an entire vessel. -Requires continuous data integration from multiple sources to stay accurate. -Still a conceptual model with few, if any, full scale implementation in shipping.

Source: By Author (2025).

Table 2 Core Data Entities and Attributes of the Maritime Asset Passport (MAP)

Entity	Key Attribute	Data Type/Description	Purposing in Enabling Circularity
Asset (Central Entity)	Asset_ID	Unique, immutable identifier (UUID).	Serves as the universal digital fingerprint for the component across its entire life-cycle.
	Serial_Number	Manufacturer's serial number	Links the digital record to physical object
	Name_Model	Commercial name and model designation	Provides basic identification for stakeholders.
	OEM	Original Equipment Manufacturer details.	Identifies the responsible producer and potential service provider
	Bill_of_Materials (BOM)	Structured list of sub-components and material composition (using standard taxonomies e.g., EU's Materiom).	Critical for recycling: Enables precise material recovery and sorting. Informs recyclers of hazardous substances.
	Installation_Date	Date of first installation on a vessel.	Helps to calculate asset age and lifecycle stage.
	Current_Condition_Index	A calculate or assessed metric (e.g., 0-100) based on sensor data and maintenance history.	Core to valuation: Provides an objective measure of remaining useful life, crucial for resale, remanufacturing, or reuse decisions.
	Recommended_Circular_Pathway	System-generated suggestion (Reuse, Remanufacture, Recycle).	Guides stakeholders towards the highest-value end-of-life option based on asset data.
Vessel_Link (Relationship)	Vessel_ID	Foreign key linking to a vessel registry (e.g., IMO number).	Contextualises the asset's operational history and location.
MaintenanceLog (Linked Entity)	Log_ID	Unique identifier for each maintenance event.	Creates a verifiable history.
	Event_Date	Date of the maintenance/repair	
	Event_Type	Classification (e.g., routine service, major overhaul, part replacement).	Build trust for remanufacturing: Complete log proves proper care and reduces buyer risk.
	Description_Parts_Replaced	Detailed notes and list of any components replaced.	Updates the effective BOM of the main asset.

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26feb663

	Performing_Entity	Company or crew responsible	Ensures accountability and traceability.
OwnershipRecord (Linked Entity)	Record_ID	Unique Identifier for each ownership transfer.	Establish a chain of custody.
	Jurisdiction	Relevant legal jurisdiction at time of transfer.	
Stakeholder (Linked Entity)	Stakeholder_ID	Unique identifier for companies/entities (OEM, Owner, Recycler, etc.)/	Manages data access permissions and roles within the system.
	Role	Defined role (e.g., ShipOwner, Certified Recycler, Regulatory Body).	Controls what data each user can view or edit, addressing privacy concerns.

Source: By Author (2025).

➢ Note:

The table presents the primary data entities constituting the MAP data schema, including asset identification, lifecycle history, ownership provenance, and end-of-life status.

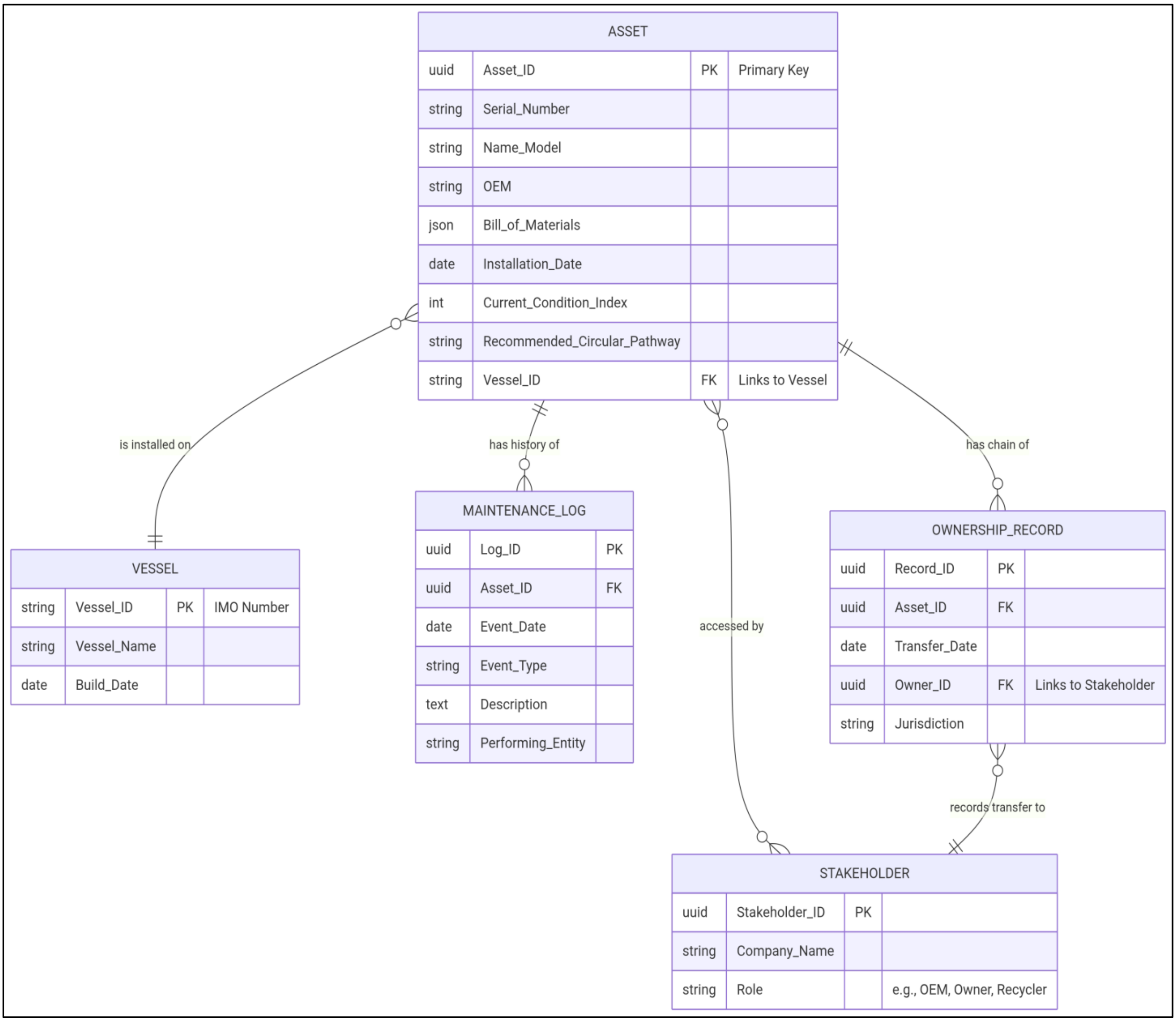

Fig 1 Entity-Relationship Diagram (ERD) visualizing the core data structure of the Maritime Asset Passport (MAP), Based on the Detailed Table 2.
Source: By Author (2025).

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26feb663

Table 3 UML Class Definitions and Relationships in the Maritime Asset Passport Architecture

Class Name	Key Attributes (Data Type)	Description & Purpose	Relationships with Other Classes
Asset	- assetId: UUID (Primary Key) - serialNumber: String - nameModel: String - oem: String - billOfMaterials: JSON - conditionIndex: Float - circularPathway: String	The central class representing any physical component (engine, generator, hull section) tracked for circularity. Its attributes store the unique identity, static specs, and current state.	- vessel: Vessel (Many-to-One) - maintenanceLogs: List<MaintenanceLog> (One-to-Many, Composition) - ownershipHistory: List<OwnershipRecord> (One-to-Many, Composition) - stakeholders: List<Stakeholder> (Many-to-Many)
Vessel	- imoNumber: String (Primary Key) - name: String - buildDate: Date	Represents a ship. Provides the operational context and parent structure for Asset objects.	- assets: List<Asset> (One-to-Many) Relationship: An Aggregation. A Vessel "has" Assets, but an Asset can exist independently if removed.
Maintenance Log	- logId: UUID (PK) - eventDate: Date - eventType: String - description: Text - performingEntity: String	An immutable record of a maintenance event. This class is composed by an Asset, meaning its lifecycle is tied to the asset.	- asset: Asset (Many-to-One) Relationship: Composition (Asset ◀◆ MaintenanceLog). If the Asset is deleted, its logs are also deleted.
OwnershipR ecord	- recordId: UUID (PK) - transferDate: Date - jurisdiction: String	An immutable record of a change in ownership or custody. Like MaintenanceLog, it is composed by an Asset.	- asset: Asset (Many-to-One) - stakeholder: Stakeholder (Many-to-One) Relationship: Composition with Asset; Association with Stakeholder.
Stakeholder	- stakeholderId: UUID (PK) - companyName: String - role: ENUM (e.g., OWNER, OEM, RECYCLER, REGULATOR)	Represents an organization or entity that interacts with assets. The role attribute is critical for defining data access permissions.	- accessedAssets: List<Asset> (Many-to-Many) - ownershipRecords: List<OwnershipRecord> (One-to-Many) Relationship: Association. Stakeholders have permissions to access/assets, but neither depends on the other for existence.

Source: By Author (2025).

➢ *Note:*

The table outlines key system classes, attributes, and relationships derived from the UML class diagram, illustrating the structural logic of the MAP database framework.

- *Key UML Relationship Symbols Explained for the Table:*

✓ Association (-): A basic, bidirectional link between two independent classes (e.g., a Stakeholder is linked to Assets it can access).

✓ Aggregation (◀-○): A "has-a" relationship where the child (Asset) can exist independently of the parent (Vessel). Denoted in the table as "One-to-Many, Aggregation".

✓ Composition (◀◆): A strong "owns-a" relationship where the child's lifecycle is dependent on the parent. If the parent (Asset) is deleted, its composed children (MaintenanceLog, OwnershipRecord) are also deleted. Denoted in the table as "One-to-Many, Composition".

This UML-based table provides the precise specification needed to translate the MAP concept into a software system, directly supporting the system architecture objectives of your research and offering a replicable blueprint for implementation.

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26feb663

Table 4 Scenario-Based Evaluation of MAP-Enabled Circular Economy Outcomes

Evaluation Dimension	**Scenario A: High-Value Component Remanufacturing**	**Scenario B: Optimized Material Recycling**
1. Current State (Linear Model)	Process: Auxiliary engine is sold as part of end-of-life vessel scrap. Recycler lacks maintenance data, assumes worst condition, and offers low "core" price based on scrap metal weight. Outcome: Engine is often shredded. Economic value and embedded energy are lost. High-quality manufacturing is reduced to low-grade material.	Process: Ship recycler receives vessel with minimal data. Steel hull is cut and shredded in bulk. Mixed steel grades and coatings contaminate the output stream. Outcome: Output is downcycled as low-grade scrap. Hazardous materials may be poorly managed. Lost potential for high-integrity recycled steel.
2. MAP-Enabled Process	Process: Recycler queries the engine's unique Asset_ID in the MAP prior to purchase. System provides full MaintenanceLog, conditionIndex, and OEM specifications. Decision: Data confirms suitability for remanufacturing. A fair price is negotiated based on verified remaining value.	Process: Recycler scans hull section Asset_ID. MAP provides the precise billOfMaterials (BOM), specifying steel grades, alloys, and coating types. Decision: Disassembly and sorting are planned digitally to separate materials by type and quality before physical work begins.
3. Key MAP Data Utilized	Asset.conditionIndex, MaintenanceLog.eventHistory, Asset.oemSpecifications	Asset.billOfMaterials, Asset.materialComposition
4. Enabled Circular Outcome	Reuse/Remanufacturing: Component is refurbished to "as-new" standard and re-enters the market with a new warranty.	High-Value Recycling: Clean, sorted steel fractions are sold as high-quality feedstock for new production (e.g., new shipbuilding), closing the material loop.
5. Quantifiable Benefits	• Economic: 50-70% of new part cost saved (Jiang et al., 2023). • Environmental: Up to 80% reduction in energy use and GHG emissions versus new manufacturing. • Strategic: OEM gains new service revenue stream; shipowner captures residual value.	• Economic: Premium price for classified recycled steel vs. shredded scrap. • Environmental: Reduced virgin ore extraction and lower processing energy. • Compliance: Automated documentation for regulations (e.g., EU Ship Recycling Reg.).

Source: By Author (2025).

➢ *Note:*

The table compares conventional practices with MAP-enabled processes across remanufacturing and recycling scenarios, emphasizing improvements in information availability, trust, and circular value retention.

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26feb663

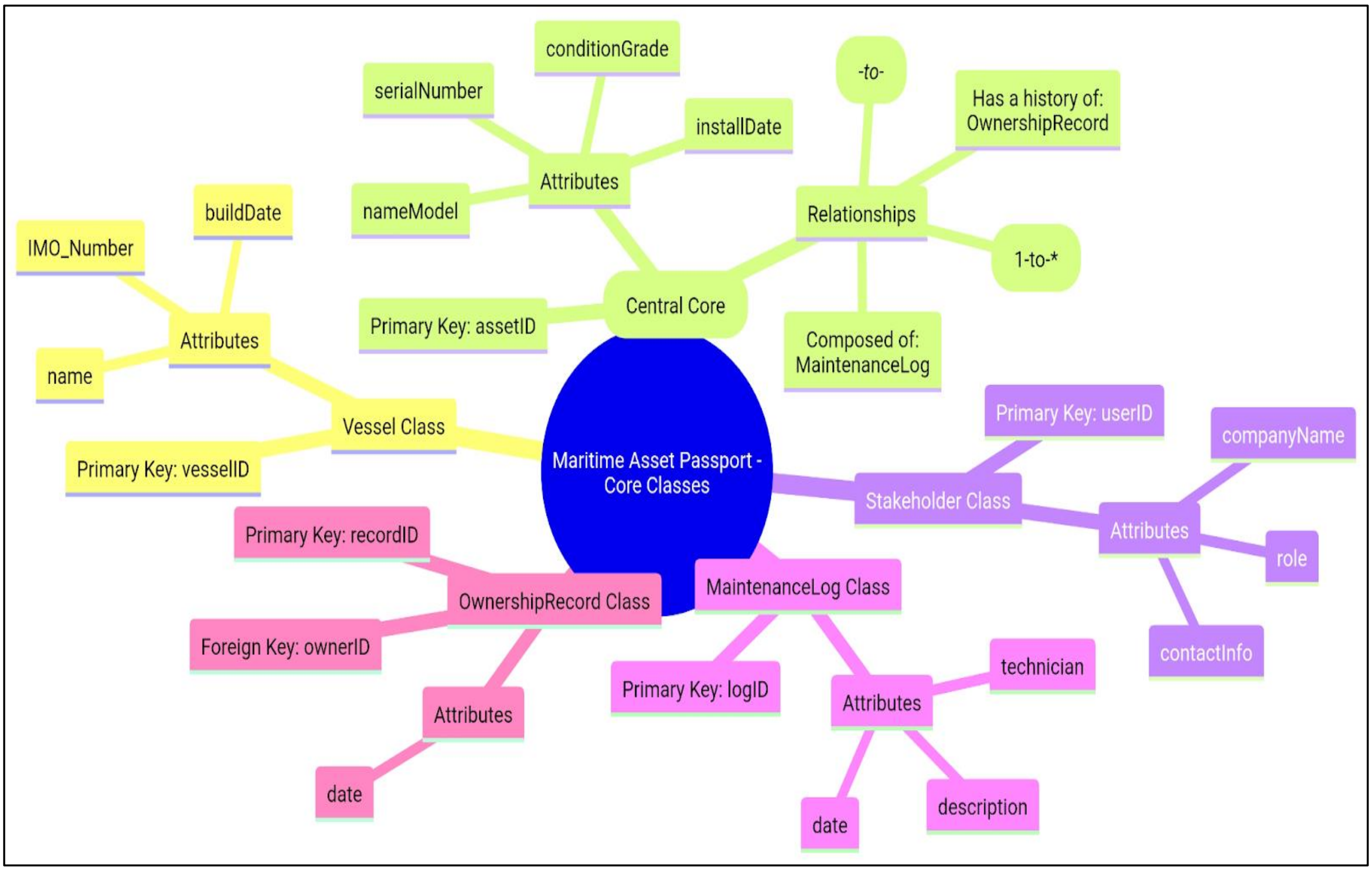

Fig 2 UML Class Diagram (Structural Model)
Source: By Author (2025).

➢ *UML Class Diagram (Structural Model):*

This diagram (Figure 2) defines the static structure of the MAP system, showing the key classes (entities), core classes of data schema, showing their key attributes and the type of relationships that connects them. Providing a clear, hierarchical view of the MAP's data structure.

PK = Primary Key, FK = Foreign Key

The diagram shows that one Vessel can have many Assets, and one Asset can be linked to many Stakeholders (owners, maintainers). The Asset class is central, with composition relationships to MaintenanceLog and OwnershipRecord.

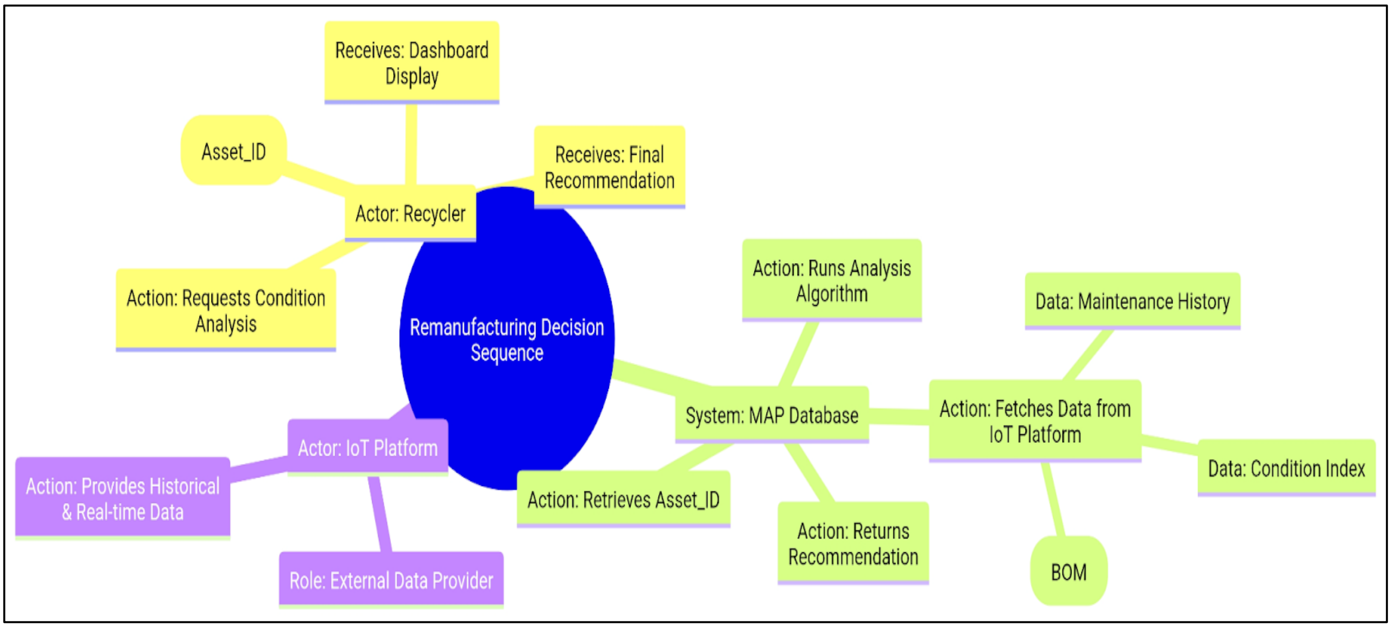

Fig 3 UML Sequence Diagram: Remanufacturing Decision Support
Source: By Author (2025).

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26feb663

This sequence Mind Map diagram illustrates how a Recycler interacts with the MAP system. The query triggers the system to fetch data from both its internal database and an external IoT platform, synthesizes it, and returns a actionable recommendation to the user.

➢ *UML Sequence Diagram (Behavioral Model):*

This diagram(Figure 3) models the dynamic interactions between system actors for a key process: querying an asset for a remanufacturing decision.

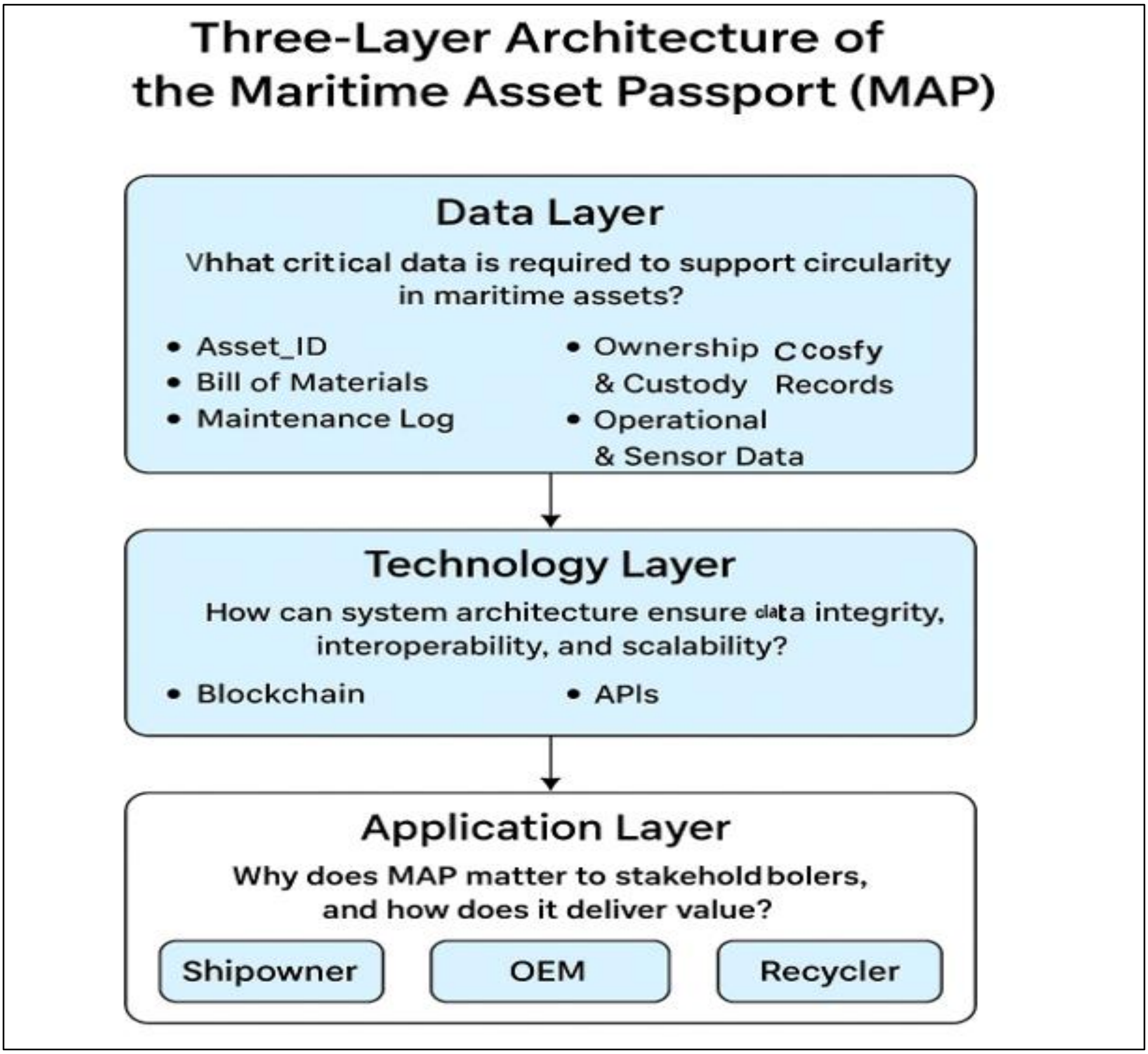

Fig 4 The Three-Layer Architecture of the Maritime Asset Passport
Source: By Author (2025).

REFERENCES

[1]. Acciaro, M., & Wilmsmeier, G. (2023). Digitalization and sustainability in maritime supply chains. *Maritime Economics & Logistics*, *25*(1), 1–24.

[2]. Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101.

[3]. Bressanelli, G., Visintin, F., & Saccani, N. (2023). Circular economy and digital technologies: A review of their synergies. Journal of Cleaner Production, 395, 136420.

[4]. Carrasco, P., van der Vlies, K., & Grosso, M. (2023). Blockchain for the safe and environmentally sound recycling of ships: A conceptual framework. Marine Policy, 148, 105441.

[5]. Dev, A., Tsai, Y.-T., & Kumar, V. (2024). Unlocking value in end-of-life ships: A circular

economy perspective. Resources, Conservation and Recycling, 190, 106845.

[6]. Fumbuka, G. J. (2025). Digital pathways to maritime circularity: A database solution for asset tracking and waste reduction [Unpublished manuscript]. Department of Business Administration, INTI International University and Colleges.

[7]. Fumbuka, G. J. (2025). Closing The Loop: Policy, Technology, and Economic Drivers for Circular Maritime Economy [Unpublished manuscript]. Department of Business Administration, INTI International University and Colleges.

[8]. Goldkuhl, G. (2012). Pragmatism vs. interpretivism in qualitative information systems research. European Journal of Information Systems, 21(2), 135–146.

[9]. Gray, C., & Charter, M. (2023). Remanufacturing and the circular economy. Routledge.

[10]. Gregor, S., & Hevner, A. R. (2013). Positioning and presenting design science research for maximum impact. MIS Quarterly, 37(2), 337–355.

[11]. Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design science in information systems research. MIS Quarterly, 28(1), 75–105.

[12]. International Organization for Standardization. (2021). ISO 14040: Environmental management—Life cycle assessment—Principles and framework. ISO.

[13]. Jiang, Z., Zhou, T., Zhang, Y., & Wang, Y. (2023). Economic and environmental assessment of marine engine remanufacturing based on a real-world case. Journal of Cleaner Production, 414, 137512.

[14]. Kirchherr, J., Yang, N.-H., Schulze-Spüntrup, F., Heer, M. J., & Hartley, K. (2023). Conceptualizing the circular economy: An analysis of 114 definitions. Resources, Conservation and Recycling, 197, 107415.

[15]. Kouhizadeh, M., Zhu, Q., & Sarkis, J. (2024). Blockchain and the circular economy: A comprehensive review and research agenda. Resources, Conservation and Recycling, 192, 106923.

[16]. Lee, J., Park, S., & Dalenberg, D. R. (2024). A machine learning approach for end-of-life vessel decision management. Journal of Cleaner Production, 434, 140025.

[17]. Poulakis, Y., & Papadakis, I. S. (2024). Green ship recycling: A review of current practices and future directions. Journal of Cleaner Production, 434, 140123.

[18]. Shin, S.-H., Jeong, B., & Zhou, P. (2023). A systematic review of ship recycling and its implications for the circular economy. Ocean & Coastal Management, 242, 106689.

[19]. Svensson, S., & Baumann, H. (2024). The digital product passport: A tool for a sustainable circular economy? Journal of Industrial Ecology, 28(1), 25–38.

[20]. UNCTAD. (2023). Review of maritime transport 2023. United Nations Conference on Trade and Development.

[21]. Webster, J., & Watson, R. T. (2002). Analyzing the past to prepare for the future: Writing a literature review. MIS Quarterly, 26(2), xiii–xxiii.

[22]. Zhang, A., & Fung, K. F. (2024). Towards a circular shipping economy: A digital twin-enabled platform for ship lifecycle management. Transportation Research Part E: Logistics and Transportation Review, 181, 103367.

[23]. Zhou, X., Zhang, Y., & Jiang, Z. (2023). A digital-twin-driven approach for remanufacturing decision of marine equipment. Advanced Engineering Informatics, 56, 101963.