IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

Circular Economy Meets Lean: Redesigning Sohar Port's Marine Supply Chains For Zero Waste

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Abstract

This research investigates the integration of circular economy principles with lean manufacturing practices to achieve zero-waste operations in the maritime supply chains of Sohar Port, Oman. Employing a quantitative methodology, the study surveys 100 maritime professionals to assess current waste streams, organizational readiness, economic and environmental impacts, and performance measurement preferences. The findings reveal exceptional awareness of waste issues across multiple operational domains and demonstrate unanimous support for sustainable transformation. High correlations among waste awareness, integration readiness, economic and environmental benefits, and measurement system adoption underscore the viability of the integrated circular-lean framework. The study identifies significant opportunities for implementing comprehensive waste management systems, establishing centres of excellence, deploying advanced measurement tools, and fostering strategic partnerships to enhance sustainability. The results also highlight the critical role of organizational culture, leadership support, and cross-departmental collaboration in enabling successful implementation. These insights contribute to the literature by evidencing high readiness levels in a Middle Eastern port context, contrasting with common assumptions about implementation challenges. Practical recommendations for Sohar Port include integrated system deployment, capability building, performance monitoring, and stakeholder engagement strategies. Future research directions emphasize longitudinal studies, comparative analyses across ports, and exploration of digital enablers and organizational factors affecting sustainability transformations. The study advances understanding of circular economy application in maritime logistics, offering a roadmap for sustainable port operations aligned with Oman's Vision 2040.

Keywords: Circular Economy, Economic Impact, Environmental Impact, Lean Manufacturing, Maritime Supply Chains, Organizational Readiness, Performance Measurement, Sohar Port, Sustainability, Zero-Waste Operations

I. INTRODUCTION

The maritime supply chain, an instrumental component of global commerce and economic development, is simultaneously struggling to comply with eco-friendly regulations while managing resource and cost efficiency. The circular economy is a new paradigm set to transform resource utilization while decreasing waste and building regenerative systems (Ruzive et al. 2023). It, in combination with lean manufacturing, which focuses on process improvement, creation of value, and elimination of waste, facilitates an effective framework of sustainable marine logistics (Hamed Khawka, 2024).

The study examines the potential benefits of a relationship between lean and circular economy in the redesign of marine supply chains at Sohar Port by aiming at zero waste, not at the expense of operational performance and, therefore, economic competitiveness. Sohar port is strategically located in Oman, and it contributes significantly to maritime activities in the region since it operates a wide variety of cargo including containers, bulk commodities, and petrochemicals (Nor et al., 2024). Unusual conditions in which the port operates pose great challenges and at the same time offer huge opportunities to develop and implement robust sustainable supply chains associated with the goal set within Oman Vision 2040 through establishing the Sultanate as one of the green and circular maritime hubs in the Arabian Gulf region (Otasowie et al., 2024).

Background of the Study

The marine logistics environmental effect has provoked a new global movement to convert the supply chain to non-linear systems of recovery, reuse, and recycle assets and supplies. Circular economy efforts have gained momentum globally as seen with the Circular Economy Action Plan developed by the European Union which has a detailed agenda of making its member states move towards a sustainable pattern of production and consumption.

A notable maritime example is Copenhagen Malm Port, which successfully implemented closed-loop waste management processes by converting marine waste into biogas and energy, significantly reducing environmental footprint while improving port energy security. Guided by international standards, Oman has initiated the adoption of a circular economy by developing national green and circular economic roadmaps and commissioning the first Circularity Gap Report in the Middle East (Jacob, 2024).

Sohar Port, Oman's largest industrial port, is a strategic hub for the country's diversification efforts, and revolutionary sustainability projects are currently being implemented for the port's activities. The application of the circular economy concept will require the implementation of circular-lean end-to-end supply chains that turn waste into valuable feedstocks and the application of sophisticated digital technologies, including real-time situation awareness and predictive analytics, for resource and decision model optimization. Such comprehensive approaches are anticipated to enhance supply chain resiliency and competitiveness while reducing waste generation (Sabah Mariyam et al., 2022).

Concerns regarding the environment and ecology influenced by marine logistics have triggered a global shift towards developing a non-linear, regenerative model for supply chains, wherein recovery, reuse, and recycling of materials and resources take precedence.

This strongly reinforces the importance of adopting a circular economy in the global market as an effective means of addressing inefficiencies and waste reduction across all sectors of the economy, including the maritime sector. A case in point is the effective implementation of closed-loop waste-management system at Copenhagen Malm Port where marine waste can be converted into biogas and energy which can significantly reduce the environmental impact of the port and enhance energy security.

Oman is driven by the global best practices to pursue pillar projects that integrate the concept of the circular economy as part of its national policy. This initiative is best illustrated by the release of the first Circularity Gap Report and the creation of the strategic roadmaps to promote green and circular economic development in the region.

As the largest industrial port in Oman, Sohar Port spearheads the nation's efforts in economic diversification while simultaneously advancing its sustainability initiatives. The idea of circularising Sohar port focuses on developing a circular Sohar Port system in which waste generated from Sohar Port circular is turned waste into resources while making use of modern technologies such as situational awareness and telemetry for decision making and real-time resource optimization.

The implementation of these systems is expected to positively impact the sustainability of the marine supply chains through improved resiliency, reduction of waste emission, and overall competitiveness. Moreover, circular practices in the economy also bring additional savings, better functioning, enhanced environmental outcomes, as well as aligning with the still industrial development goals of the country.

The region-specific systems for waste management, reverse logistics, and new technologies pose some challenges in the shift to the maritime industry. However, these obstacles do bring the potential for great innovative collaborations with the stakeholders.

Problem Statement

The current marine supply chains operating in Sohar Port require more improvement in terms of inefficiency and streams of waste that hamper fulfilment of zero waste and operational excellence aspirations of the same. Waste management has been piecemeal, with most processes being linear, and there is inadequate use of digitization to stimulate real-time optimization of processes and coordination of supply partners along the supply chain (Astadi Pangarso et al., 2022).

Furthermore, there is also a severe shortage of applicable models and empirical evidence on how the concepts of circular economics could be built into the marine logistics situation in Oman in a procedural way especially in conjunction with the concept of lean manufacturing. This gap constrains industry stakeholders

such as the port authority, logistics operators, and policymakers to make effective businesses to reform marine chains of supply into regenerative chains with zero-waste operations that are supported with national environmental and economic goals (Soni et al., 2025).

Research Aim

The study is limited to defining how to design a cohesive circular economy and lean manufacturing model for reengineering the marine supply chains of Sohar Port with a zero-waste goal by upholding competent business processes and creating sustainable competitive advantages in the maritime sphere of the state of Oman (Ayda Shamsaei, 2025).

Research Objectives and Questions

To achieve this aim, the study focuses on the following objectives:

1. To identify current waste streams and inefficiencies in Sohar Port's marine supply chains
2. To establish a framework for integrating circular economy principles with lean manufacturing practices
3. To examine the economic and environmental impact of implementing circular-lean systems
4. To develop performance measurement tools for zero-waste supply chain operations.

Research Questions

- RQ1: What are the current waste streams and operational inefficiencies in Sohar Port's marine supply chains?
- RQ2: How can circular economy principles be effectively integrated with lean manufacturing practices in maritime operations?
- RQ3: What are the economic and environmental impacts of implementing circular-lean systems in port operations?
- RQ4: What performance measurement tools are required to achieve zero-waste supply chain operations in maritime contexts?

Significance of the Study

This research contributes to closing the gap in knowledge and practice regarding sustainable supply chain transformation in the maritime sector of Oman and similar emerging markets. Specifically, it:

- **Advances Academic Knowledge:** By combining circular economy and lean manufacturing theories within a maritime context, the study expands the theoretical framework and offers a novel perspective on sustainable supply chain design.
- **Supports National Development Goals:** The findings and frameworks developed will align with Oman Vision 2040, promoting economic diversification through green industrial initiatives and positioning Sohar Port as a regional leader in sustainable maritime operations.
- **Benefits Industry Stakeholders:** Practical implementation tools, cost-benefit analyses, and risk assessments derived from the study will equip port operators, logistics firms, and policymakers with evidence-based strategies to transition toward zero waste.
- **Encourages Technological Innovation:** By emphasizing advanced digital technologies for real-time supply chain visibility and decision-making, the research underlines the role of Industry 4.0 solutions in achieving circular-lean operations.
- **Supports Environmental Sustainability:** Reducing waste and resource consumption in maritime logistics will contribute to global efforts in mitigating climate change, protecting marine ecosystems, and promoting responsible resource management.

Scope of the Study

The study's focus is on Sohar Port, as it is Oman's largest industrial maritime hub with complex and diverse supply chain activities. The research adopts a **temporal scope from 2015 to 2025**, analyzing recent trends, patterns, and initiatives related to circular economy and lean implementations within the port's marine supply chains.

Methodologically, the study relies on **primary quantitative data collection** through surveys targeted at approximately 100 maritime professionals across Oman's major ports, including Sohar, Salalah, and Duqm. Respondents will include supply chain managers, port operations staff, logistics coordinators, environmental managers, and senior executives involved in marine logistics operations.

The geographical focus on Oman's ports allows for an in-depth, contextualized exploration of marine supply chain practices within the emerging circular economy framework.

II. LITERATURE REVIEW

Introduction

The literature review interrogates the interplay between circular economy principles and lean manufacturing practices within maritime supply chains through both theoretical and empirical lenses. By collating and analyzing scholarly contributions, the chapter elucidates how these two paradigms jointly undergird strategies designed to minimize resource consumption and enhance port-based efficiency. Evidence drawn from port resource recovery case studies, lean supply chain modelling, marine waste minimisation, and sustainability-oriented performance metrics is aggregated to expose synergies, seams, and the trajectory toward zero-waste ship-to-berth networks. The review is sequenced to interrogate existing performance, to test conceptual rigour, to confront operational complications, and to benchmark analytic indictors that collectively guide the conceptualisation of null-waste supply activities within the operational fabric of the maritime economy.

Founded upon a homogeneous linear model, maritime activity has predominantly embroiled the sequence of extract-transform-throw, bestowing an inbuilt obsolescence upon the distinctive physical artefacts of the marine value chain. Socio-ecological and situational pressures—ranging from tightened attenuation of pollution through ESDR regulation to the denudation of operational variegates—cordially augment the drift from a unilateral, ex-vessel finality to a modal syntax of perpetual service. The incorporation of circular economy logic with the waste-minimisation mechanics of lean manufacturing thus becomes a logistic aperture through which combined resource conservation and efficiency aimed at cumulative marine benefit is increasingly empirically attainable.

The literature reveals that while individual applications of circular economy and lean principles have been extensively studied, their integrated application in maritime contexts remains relatively underexplored. This gap is particularly pronounced in emerging market contexts such as the Middle East, where ports like Sohar are seeking to balance rapid industrial growth with environmental stewardship. The review therefore focuses on identifying theoretical frameworks, practical applications, and measurement approaches that can inform the development of integrated circular-lean systems for marine supply chains.

Circular Economy Principles in Maritime Operations

The circular economy signals a paradigmatic departure from the linear models that have long underpinned the maritime sector, where the progression from resource extraction to waste disposal has been normatively affirmed. Within maritime systems, adherence to circular economy precepts converges upon three interleaving imperatives: first, the pre-emptive design of port and maritime operations to sever the channels through which waste and harmful substances enter the environment; second, the sustained, value-preserving circulation of vessels, components, and cargo through deliberate, regenerative cycles that recover, remanufacture, and repurpose; and third, the deliberate reinforcement of marine ecosystems, such that their resilience and economic productivity co-evolve (Dogancan Okumus et al., 2023). Collectively, these

imperatives disrupt the entrenched take-make-dispose paradigm that has rendered maritime logistics a linear conduit of resource throughput, waste generation, and, inevitably, ecological intervention (Dogancan Okumus et al., 2024).

Maritime operations qualify as an exemplary proving ground for circular economics due, in substantial part, to their capacity to consolidate poly-modal, industrial, and logistical activities within fixed geospatial and operational boundaries while simultaneously sustaining extensive interchanges of materials and energy. Port infrastructure, by design and circumstance, serves as a highly functional merging zone in which different transport modalities, multifarious manufacturing and service archetypes, and variegated waste streams coalesce (Jensen et al., 2021).

Energy recovery systems present an equally vivid exemplification of circular economy logic in contemporary maritime action. At most major port facilities, a considerable volume of organic residuals arises from galley operations aboard vessels, from ship services, from terminal-based catering, from maintenance of green areas, and from receipt of transient freight. Innovatively engineered anaerobic digestion facilities harness these streams, sequestering them in controlled, low-oxygen environments, thus converting them to biogas (Damoon Razmjooei et al., 2023). The resultant biogas may then be combusted in reciprocating engines to produce in-situ electricity for terminal operations, or subject to intermediate purification and upgrading to biomethane, supplying low-carbon fuel for terminal vehicles, service craft, and delivery trucks. Concomitantly, port-integrated waste-to-energy reactors thermally or thermochemically valorise combustibles diverted from landfill, yielding a controlled enthalpy of steam or electricity, depending on the specific rendering architecture (Dogancan Okumus et al., 2022). In each operational model, thermal or electrical dispersal diminishes reliance on imported fuels, while simultaneously lowering the total expenditure associated with municipal disposal and with grid-sourced power. Cumulatively, these interventions alleviate the volume and typicity of land-based waste, propagate measurable increments in port system energy independence, and contribute to the progressive circumnavigation of carbon emissions, thus opposing the deduction of the port terminal carbon balance and corroborating the region's strategic decarbonisation and societal stewardship nexus (Viktoriia Koilo, 2025).

In maritime operations, digital technologies fundamentally advance the deployment of circular-economy principles by furnishing the requisite visibility, coordination, and optimization capacities for the administration of intricate material trajectories and recovery architectures (Viktoriia Koilo, 2025). By employing Internet-of-Things sensors, stakeholders continuously monitor the movement of resources, the generation of waste, and the consumption of inputs, thereby revealing actionable efficiencies and facilitating aligned circular activities across terminal, loading, and processing domains. Complementary advanced-analytics platforms aggregate and interrogate these datasets to forecast waste-generation trajectories, to fine-tune collection and processing timetables, and to surface emergent streams suitable for recovery and secondary use (Raja and Tangkau, 2022). Furthermore, distributed-ledger technologies such as blockchain

afford immutable and verifiable trajectories for resources traversing circular pathways, thereby ensuring material quality and safety and simultaneously bolstering stakeholder trust in the integrity of circular-value chains.

Achieving the successful application of circular economy principles in maritime activities mandates a degree of stakeholder co-operation that transcends the conventional confines of port authority jurisdiction. Vessel operators, supply-chain integrators, cargo holders, waste-processors, energy-service firms, and technological solution architects must collaborate in concert in order to design harmonised systems that both yield economic surplus from otherwise discarded resources and raise the overall level of operational productivity (Nilsen, 2019). Such co-operation frequently hinges upon the co-creation of novel business frameworks, the co-funding of shared logistic and production assets, and the adoption of co-ordinated operational protocols that reconciliate the divergent priorities of various stakeholders with clearly articulated circular goals. The systemic intricacy of these multi-actor arrangements entails the simultaneous establishment of advanced governance regimes, comprehensive performance indicators, and multi-horizon risk-control frameworks that in tandem assure enduring sustainability and confer demonstrable, asymmetrically shared value to every actor within the circular economy interface (Nilsen, 2019).

Lean Manufacturing in Supply Chain Management

The automotive industry is where lean manufacturing principles began but now they have been adapted successfully to a variety of other industries like maritime logistics and supply chains. The fundamental philosophy guiding lean manufacturing is the maximization of the customers' value while minimizing the wastes involved in the process through continuous improvement. In supply chains, lean principles focus primarily on value stream optimization, waste elimination, and multi-tiered systematic problem-solving (Rossini, Powell and Kundu, 2022).

In the maritime supply chains, the wastes identified are the underutilized transportation waste due to inefficient routing, inventory waste due to the holding of excess stock, motion waste due to the unneeded movement of materials and personnel, waiting waste due to the waiting delays and blocking of funnels, overprocessing waste due to unneeded steps, overproduction waste due to excessive excess, and defect waste due to errors in redoing. These forms of waste provide a robust systematic structure to analyse the inefficiencies in the maritime supply chains (Assadej Vanichchinchai, 2019).

The systematic approach to lean integration in maritime surrounds the use of value stream mapping, value streams, and the workflows in the streams to track the steps that have improvement hidden in them. The following phases employ a wide range of lean tools where the value streams, lean tools and the workflows in the streams are used to accomplish the goal. Some of the tools focus on workplace discipline like the 5S of lean, the JIT approach to logistics, the multi-cycle continuous improvement approach, the satanized task approach, and the visual management approach. These chains of tools in the supply are now characterized by improved and predictive reliability (Tay and Loh, 2021).

Integration Framework for Circular-Lean Systems

When lean manufacturing is combined with circular economy principles, both ecological and productivity performance are further enhanced. However, the effective realization of this dual approach still requires the establishment of integration frameworks that are explicitly specified. Such frameworks must elucidate the complementary advantages that stem from the conjoined application of lean and circular economy metrics and must engineer a stable coexistence between lean's iterative, cost-driven imperatives and the circular economy's systemic, resource-leading directives (Tay and Loh, 2021).

Existing theoretical frameworks often privilege waste denial as the foundational construct, yet a precise and rigorous delineation of waste is indispensable. From a circular economy standpoint, waste is recognized primarily in relation to resource valorisation through modelling and computation, whereas the circular economy dimensions approach waste through the architectural design of material circularity, closed reversibility, and recoverable streams. Integration architecture when conceived through rational design permits the concurrent accomplishment of both lean latency and circular economy modelling by scheduling constrained optimisation paths that deliver profit-optimal throughput, superior yield, declining resource load, and reversible, material regenerative loops (Awan et al., 2022).

Conceptual frameworks supplemented by empirical literature indicate repeated pathways through which integration is operationalized. They comprise: redesign of cross-functional processes that simultaneously advance temporal productivity and elevate material recirculation; modular information-technology platforms that fuse just-in-time logic with continuous material-tracking; balanced performance dashboards that align Net Operating Profit stewardship to waste diversion and virgin-resource savings; governance architectures that embed both lean and circular champions within the identical operational echelon; and structured dialogue with both upstream and downstream partners that collaboratively co-construct ecosystem-wide value propositions upon shared imperatives. Each of these processes corroborates integration's compounded capacity to fulfil, concurrently and within manufacturing contexts, fiscal, operational, and environmental objectives (Khorasani, 2019).

Integrating the goals of Lean and Circular economies tends to require solving competing imperatives which otherwise hinder progress. One such instance is when Lean tries to promote the minimizing of in-process inventories and imposition of Just-in-time delivery, while the Circular approach considers the strategic retention of recyclable substrates and spare components for remanufacture to be a dominant secondary imperative. Integration techniques are expected to develop control measures whose optimization criteria are holistic to the system, as opposed to lean throughput and circular yield recovery as independent ends (Khorasani, 2019).

An equally salient consideration is the juxtaposition of divergent temporal horizons and investment frameworks. Accelerated financial returns characterise the yield of well-executed lean refinements, whereas circular commits typically incur protracted amortisation schedules (Ali et al., 2020). Nevertheless, the latter

alternatives afford augmented mitigation of ecological externalities extending well beyond the duration of the lean return. A robust integration construct must, therefore, synchronise the juxtaposed profiles through a canonical business case that conveys balanced economic and environmental calculated returns.

Furthermore, the governance of change must incorporate a blended capability in lean and circular expertise, for operational and environmental enhancements are being layered upon one another rather than sequenced. A successful approach entails fortifying the organisation's proficiency in both value-stream oversight and resource-loop optimisation, chartering cross-functional task forces, and instituting governance frameworks competent to track portfolio performance against multiple, converging improvement trajectories (Yugowati Praharsi et al., 2021).

Zero Waste Concepts and Waste Stream Management

Zero waste at sea constitutes a rigorous policy orientation that transcends punitive disposal practices, envisioning instead the rotation of resources within a regenerative cycle. Implementation within the maritime sector necessitates the stepwise establishment of data-driven tracking of all material discards, the design of closed-loop valorisation curricula, and the encoding of waste disavowal into everyday navigational and operational directives.

Cross-institutional surveys confirm that the sector is besieged by a spectrum of waste categories: galley and catering activities release volatile organic fractions; cargo operations and domiciliary stores shed multilayer films and cores; maintenance regimes yield composite filters and coatings; port and vessel yard refurbishment generates static and ballast debris; volatile hydrocarbon and chemically reactive residuals arise incidentally from bunkering rounds; and all on-shore and on-board administrative activities disperse paper, electronics, and packaging residues (Yugowati Praharsi et al., 2021). Each of these streams allocates a distinctive paradigm of valorisation, one that is reciprocally anchored in efficiency imperatives and planetary health observances.

Structured analysis of waste categories, derived from operationally oriented research, supplies a repeatable apparatus for delineating, quantifying, and profiling the diverse discards of a tonnage. Standard protocols combine excursion auditing within operational units, granularity of waste generation correlates, cognitive maps of genesis incentives, empirical interrogation of extant discursively and logistically positioned disposal interfaces, a ranking of facilitatory innovations toward curtailment and sink-free valorisation, and geo-spatially contextualized strategy design (José Moyano-Fuentes et al., 2020).

Zero waste operational programmes concentrate on the elimination of waste generation by re-engineering material flows, institutionalising in-plant reuse through closed-loop circulation, establishing formal recycling arrangements with off-site processors, deploying energy recovery technologies for organics and combustible fractions, and managing the safe landfill of residues that resist recovery. Application of these

methodologies generally proceeds in a ranked sequence, privileging prevention and reuse over recycling and disposal (Novais, 2020).

Creation of zero waste networks demands substantial capital outlays, particularly for waste streaming infrastructure, bulk and dynamic storage facilities, intermediate and final processing units, predictive and responsive transport logistics, real-time monitoring and data capture capabilities, and negotiated alignment with accredited waste management suppliers. Evidence in the literature identifiably asserts that successful realisation of zero waste initiatives proceeds only when planning scenarios integrate both technical imperatives and decisive economic viability (Singh, Singh and Kumar, 2020).

Systematic performance monitoring of zero waste networks systematically emphasises diversion rates, recovery efficiencies for material and energy, total witnessed cost savings, documented environmental performance gains, and continuous adherence to establishing statutory norms (Singh, Singh and Kumar, 2020). The resulting dashboards furnish managers with real-time feedback for iterative enhancement and, equally, substantiate in financial terms the return from strategic zero waste capital and operational outlays.

Performance Measurement and Digital Technologies

Performance measurement systems for circular-lean marine supply chains must capture both operational efficiency and environmental sustainability outcomes. The literature reveals that traditional supply chain performance metrics focused primarily on cost, quality, delivery, and flexibility measures, but sustainable supply chain management requires additional metrics that address environmental and social impacts (Hamre, 2021).

Integrated performance measurement frameworks typically include operational metrics such as throughput rates, cycle times, inventory turns, quality levels, and cost efficiency, alongside environmental metrics including waste generation rates, resource consumption efficiency, energy utilization, carbon footprint, and recycling rates. These metrics must be balanced to ensure that environmental improvements do not compromise operational performance and vice versa.

Digital technologies play a crucial role in enabling comprehensive performance measurement for complex supply chain systems. Internet of Things sensors provide real-time data on material flows, equipment performance, energy consumption, and environmental conditions (Nasiri, 2020). This data enables continuous monitoring of both operational and environmental performance indicators, supporting rapid identification of improvement opportunities and performance deviations.

Advanced analytics platforms aggregate and examine extensive streams of operational and environmental data to unearth underlying consistencies, forecast forthcoming performance metrics, and refine procedural efficiency (Dunayev, 2022). Embedded machine-learning algorithms detect marginal correlations between managerial interventions and environmental repercussions, facilitating the co-formation of

optimization policies that concurrently elevate operational efficiency and fortify sustainability objectives (Zaman et al., 2024).

Blockchain technology supplies the capacity to forge immutable, verifiable logbooks that chronicle the transit of materials and the associated environmental metrics throughout intricate supply-chain networks. Such persistent, transparent documentation is especially advantageous for circular-economy initiatives, wherein substances traverse multiple agents and transformation stages before reintegration.

Economic and Environmental Impact Assessment

Integration of circular-lean frameworks within maritime supply chains generates economic and environmental effects that intersect along mechanisms of prospective cost savings, anticipated revenue, planned investment, and observable ecological improvement. The predominant scholarly consensus maintains… that impact evaluation is inherently multi-dimensional and exceeds the simplistic representation it frequently receives. Such evaluation encompasses both primary and secondary effects, mandates the simultaneous consideration of heterogeneous stakeholder perspectives, and demands examination over multiple temporal scales (Deng, Duan and Wibowo, 2022).

Conventional value-focused economic evaluations concentrate on quantifying direct cost reductions attributable to waste valorisation, resource depreciation, and energy conservation realizations, together with savings embedded within the underlying processing stages (Tsou, 2023). Direct savings in process costs are also obtainable from the sales of recovered materials, recovered energy, and from certain contractual arrangements with external parties. Empirical evidence surveys indicate that circular-lean proposals achieving replicable scale often yield robust multiplicative economic gains, notwithstanding the potentially sizeable and unavoidable initial outlays.

Outlays attendant upon circular-lean adoption encompasses secured infrastructure for advanced waste valorisation and closed-loop material recovery, multifaceted information platforms, skill enhancement, organisational optic restructuring, transparent change management, and co-developed alliances with specialised external domains (Tsou, 2023). Justification of these outlays must juxtapose quantified financial yield with extraoral environmental gain to construct defensible and integrated investable business propositions, thereby allowing stakeholders to assess both exception and continuity.

Environmental impact assessment is predicated upon the formal quantification of decreases in a spectrum of adverse outputs: waste volumes, resource drawdown, energy expenditure, and greenhouse gas emissions, among other relevant ecological metrics. Complementarily, life cycle assessment (LCA) frameworks furnish a disciplined, stepwise protocol for the appraisal of environmental ramifications that extends longitudinally across the full life history of a product or service (Lyu and Liu, 2021). This first resource and cradle-to-grave analysis ensures all upstream and downstream stages and their cumulative footprints are reconciled within a single cohesive analytic boundary (Gawankar , 2020).

Gawankar (2020) asserts that positive impacts associated with ecosystem restoration from operational improvements stem from circular-lean practice and extend beyond operational boundaries to reduced resource depletion, reduced pollution and environmental degradation, improved air and water quality, and enhanced biodiversity protection.

Economists and circular-lean practitioners consider market changes and system complexity operational and market risks to be resolved. Risk assessment of operational and market balance in this context outlines a phased implementation approach, diversification of technology platforms, flexible operational systems, and stakeholder engagement processes.

The decision-making processes are enabled by the development of integrated economic and environmental models that assess the implementation risk of system designs for optimal value creation. Value creation while managing the integration risks is a controlled environment system. These models provide quantitative projections which are imperative for the decision-making frameworks that enable optimization of system design (Balakrishnan and Ramanathan, 2021).

Literature Gaps and Research Opportunities

The literature review discloses significant deficiencies concerning the understanding of integrated circular-lean systems applicable to maritime supply chains. The integration of circular economy and lean practices, particularly in the context of the Middle East, has been the subject of very little research (Balakrishnan and Ramanathan, 2021).

There is little empirical research on the outcomes of integrated circular-lean systems as most research concentrates on displaced theoretical constructs. This inhibits the development of realistic strategies and performance outcomes for circular-lean transformation which can be claimed by maritime organizations.

The literature suggests that particular types of maritime operations have not been the subject of a tailored survey which is a significant oversight. The industry is littered with studies which do not distinguish between container terminals, bulk cargo, petrochemical and other specialist maritime activities (Dilek Cetindamar, 2021).

Most research on the assessment of integrated circular-lean systems is focused on the direct operations as opposed to the encompassing environment which is the most critical element in the contemporary maritime industry. The inability of organizations to showcase the comprehensive performance of the integrated systems demonstrates the lack of understanding in the field of maritime industry (Cassetta, 2020).

Although the use of IoT, analytics, and automation technologies can help in operational and environmental objectives, the importance of these technologies in enabling integrated circular-lean systems remains unanswered in the maritime context.

The primary focus of Cassetta (2020) concentrates on the cultural and organizational facets of integrated circular-lean system focus on emerging markets and the salient differences as compared to developed markets.

The above gaps in literature are the base on which this research has been conducted, which aims to create tailored circular-lean systems for the maritime supply chain on Sohar Port and other similar emerging maritime context facilities (Shahrokh Nikou and Milla Aavakare, 2021).

III. METHODOLOGY

Introduction

This chapter presented a comprehensive overview of the research methodology employed to investigate the integration of circular economy principles with lean manufacturing practices in marine supply chains at Sohar Port. The methodology was designed to address the research objectives systematically, providing a framework for collecting and analyzing empirical data to understand waste reduction and efficiency improvements in maritime operations. The chapter outlined the research design, identified the study population, described the sampling techniques and sample size determination, detailed the research instruments used including their validity and reliability testing, explained the data collection procedures, presented the data analysis techniques employed, and addressed the legal, ethical, social, and sustainability considerations that guided the research process. The chosen and justified approaches to the study were to maximize its value added to the corpus pertaining to sustainable maritime supply chain management and provide recommendations to Sohar Port in its goal to transformative to zero-waste operations. The quantitative research approach undertaken facilitated the delimited and organized study of the associations among the definitional parameters and yielded empirical data to validate the theory established in the literature review.

Research Design

The analysis collected primary quantitative data on the interplay between integrating the principles of lean manufacturing and the circular economy in a supply chain and the resulting operational outcomes. The aim of the study directly correlated with the aim of the research conducted by Ciliberto and other scholars in 2021. Such structure is defining in the sense that measuring lean manufacturing circular interactions and their dependence on the outcome are multifaceted and the most complex in regard the theory of economic and fiscal balance systems impact on productivity ratios. The maritime industry lacks of a circular economy and lean principles readily available in other sectors. The employment of primary quantitative data on the changes that occur when circular economy and lean practices are integrated over a target single operation warrants the diverse response criteria that can be subjected to professional naval cohorts. The collection of data is within a target fragmented period. The holistic part captures the sentiments and practices on water disposal that stem from lack of a waste circular. This design structure enabled the researcher to capture representative practices

and perspectives during container port operations. The analysis is enhanced through the preceding of a domain where stimulus does not alter the behaviour system between changes and structure of operations.

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The baseline measurements which informed future longitudinal studies along with their implementation and impact of circular-lean initiatives were accomplished with high accuracy. Such accuracy is achieved through the quantitative design for statistical rigor critical for predicting hypothesis derived from the theoretical framework. It is also able to proven regarding the leaning and circular economy merging for success in the maritime context (Kalemkerian et al., 2022).

Population of the Study

The study population comprised maritime professionals working across various operational areas at Sohar Port, Oman's largest industrial maritime hub. This population was strategically selected due to Sohar Port's significance as a critical component of Oman's economic diversification strategy and its alignment with the national Vision 2040 sustainability goals. Supply chain managers allocated to the arms of materials flows and logistics operations with responsibility overlaps, as well as port operations crew members who directly and indirectly engage with cargo and vessel servicing, logistics administrators who facilitate goods transfer through the port, as well as waste and compliance managers and top-level strategists of marine logistics governance, together with all other target participants, gained their expertise from various operations. So did the technical staff, maintenance team, officers of quality control, and other administrative workers who directly and indirectly contributed to the waste, resource, and port activity control balance (Maldonado-Guzmán and Garza-Reyes, 2023). Such a wide population breadth was necessary to provide divergent views on the captured waste, and the sluggish operations of a business, alongside the utilization of the circular economy and the lean approach frameworks. Study participants within the population who occupied diverse structural levels within the organization comprising entry-tier to top-tier management positioned themselves

to reveal their expertise from various operational scopes and organizational layers. Such varied population composition was characteristic in obtaining different views on various aspects – the set of metrics of sustainability initiatives, their created hybrids, the conundrums of readiness, and the more practical among them, the assistance of converting a traditional linear supply chain to a circular-lean supply chain system.

The location of the people at Sohar port allowed for the confinement of the environment to study the particular contextual elements affecting the modification of the maritime supply chain for the Middle East region.

Sampling Technique and Sample Size

Participants who were knowledgeable and directly experienced with maritime operations, waste handling, and pack work at Sohar Port were chosen with the help of purposeful sampling. This type of sampling technique was chosen because the researcher was able to reach people who truly had the needed knowledge and experience about his research focus. The researcher was assured that the respondents will be able to answer questions the research had pertaining to circular economy and lean manufacturing integrated. The particular nature of the maritime operations and the respondents of the research who needed to evaluate the existing waste streams and operational inefficiencies, as well as the likelihood of bringing in sustainable practices warranted the use of purposive sampling. The sampling technique included ascertaining major departments and operational blocks at Sohar Port who directly participated in the handling of cargo and its subsequent logistical management, as well as the cross cutting the other departments. The respondents were chosen based on the structural and operational level of the maritime operations, the experience ladder, and the activities that were considered as waste streams or activities that raised operational effectiveness or efficiency. The various shifts, operational areas, and management levels were included in the sample to obtain diverse perspectives and to ensure that there was representativeness of the port organization. Out of the targeted sample size of 100 respondents which was successfully achieved, around 15 % were from the population of maritime professionals that were relevant at Sohar Port.

The sample size in the present study is a hundred participants, which is corroborated with the necessary sample size from a power analysis, with a focus on effect sizes in correlation analyses and adequate regression analyses, with the four main variable constructs. A sample of a hundred participants is quite adequate from the power analysis balancing trade-offs between perceptual, statistical, and practical significance of the effect size, with regression analyses reporting models of high complexity. Adequate sample sizes provided were incrementally above the elements calculated for minimum requirements for structural analysis and equational modelling techniques.

Research Instruments and Validity and Reliability Testing

For this study, a custom questionnaire was designed focusing on collection of primary data. The questionnaire was designed in a way that it is in alignment with the objectives of the research, the

accompanying theory, and findings of the literature review. The framework incorporated in this study was developed with the use of already existing scales on circular economies, lean supply chain disciplines, and maritime operational supply chain management. Refined versions of the PhD's Ports Framework is anchored around the maritime industry. The study as a whole was divided into six key sections. Integrating Lean and Circular Practices: Overcoming Barriers to Circular Lean Integration, Demographic and Socioeconomic Index, Ecological and Economical Impacts Assessment, Current Linear Waste Streams, Performance Assessment Tools for Zero Waste Operations, Unsustainable Practices of Zero Waste Operations, and Additional Recommendations. Each of the sub-sections was partitioned into questions with responses measured on a five-point Likert scale system, allowing the analysis of attitudes, beliefs, and experiences. The demographic questions aimed at capturing age, gender, educational level, years of working in the shipping industry, and the specific working sector at Sohar Port. The questions were validated with the help of experts which in this case were three academic researchers in supply chain management together with two highly experienced professionals in the maritime industry with a focus on operational ports and sustainability.

The expert's panel assessed the questionnaires concerning the clarity, relevance, and completeness of each item and revisions in the form of altering the wording of several items and adding two new ones concerning the adoption of digital technologies was made. The face validity was assessed by means of cognitive interviews with five maritime specialists who provided feedback concerning the meaning and the use of items and questionnaires. Construct validity was assessed by means of the factor analysis of the pilot test data, which confirmed the presence of the construct of the main variables. Employing the Cronbach's alpha coefficient pertaining to internal consistency as reliability assessment of the instrument at hand ascertains its reliability. The obtained reliability coefficient of Cronbach's alpha equal to 0.836 exceeds the cut off point of 0.70 as the lower threshold advocated for in social science research. This indicates the items within the questionnaire provided intern consistency. This corroborates a more current finding which maintains that the research questions and scales designed for the research obtained a quite substantial reliability level, signifying the collection instrument was reliable and valid (Kurdve and Bellgran, 2020).

Data Collection Techniques

This survey was designed to ease the economic burden of geographical surveys and at the same time provide data in stratified and cost-effective formats for subsequent statistical analysis. The survey link was made available to the target population using diverse formats and approaches and was designed to capture the target contour population. The primary means of administrating the survey was through the human resources (HR) department of the Sohar Port which was tasked with the distribution of the survey link through the company's formal internal communication such as electronically disseminated communication, employee websites, and departmental e-poster. The secondary means of instructing the target population were supervisors and department heads that in the presence of the target population during the shift change formalities and departmental assemblies. The purpose of the survey was communicated and available to the

target population in the English and Arabic language. The purpose was to maximize the response rate emanating. Members of the sample were briefed on the concept of survey responses confidentiality within the context of the research and the possibility of withdrawal without penalty. Participants were also informed that the survey, as a whole, would serve as a data collection tool for further research.

Data Analysis Technique

Data was retrieved via statistical procedures and SPSS (Statistical Package for the Social Sciences) was used for descriptive or inferential statistics at any level of complexity. The analysis had substantial cleaning and arranging steps including validation of outliers, typographical errors, and 'no response' errors. Based on the analysis, the variable demographics were stratified to validate the boundaries of the overall research focus. Then, the measures of central tendencies and variances were computed, including subsample sub variables and total score computations. The focal variables were cross checked for intervals and central tendencies of the dependent variables configured for measuring the research focal variables. To regulate the title and the content of the sentence, employ correlation coefficients per the received Hoefling's D statistics to the structures regarding currently available waste streams and integration of bottom line equations (economy + ecology) with operation measures for zero waste and circular cycles with lean manufacturing zero lean loops and performance metrics. The dependent and independent variables for the equation were economically and ecologically balanced impact and the proposed measures. Regression function analysis was used for the relational explanation.

This approach helped to identify important predictors and to gauge the amount of variance captured by the model. Within the regression analysis domain, the analysis encompassed checking the assumptions of linearity, independence, homoscedasticity, and normality of residuals. Other analyses were assessing the moderation of multicollinearity by variance inflation factors and assessing model fit with R-squared values and subsequent significance tests. Factor analysis was used to examine the confirmatory validity of the underlying structures of the measuring constructs to support construct validity. This approach also examined potential demographic moderators on the relationships of the main constructs. Statistical significance was set at 0.05 alpha with effect sizes calculated and interpreted based on the established criteria for practical significance within organizational research.

IV. RESULTS

Introduction

This chapter presented a comprehensive analysis of data derived from the survey undertaken with the maritime professionals at the Sohar Port to evaluate the association between the principles of the circular economy and lean manufacturing in the marine supply chains. The analysis started with the examination of the demographics of the respondents, then started with the analysis of the survey data longitudinally as per the four key constructs which included: current waste streams and inefficiencies, integration of the principles

of the circular economy with the lean manufacturing principles, the economic and environmental effects, and the tools for performance assessment for zero-waste operations. Graphs and tables were used in the analysis to assist the interpretation of the data and the outcomes of the study. The chapter included both descriptive and inferential statistical procedures for examining aspects of the data which included correlation, multiple regression, t-tests, and ANOVA to examine the relationships and test hypotheses.

In this final section, the climax unfolds alongside the windup in moving towards the ensuing 'discussion' chapter wherein the results shall be placed in the context of sustainable 'maritime operations' and the 'circular economy' to be discussed in wider perspectives.

Demographic Profile

Table 1 Demographic Characteristics of Respondents (N=100)

Demographic Variable	**Category**	**Frequency**	**Percentage (%)**
Age Group	20-30 years	29	29.0
	31-40 years	21	21.0
	41-50 years	18	18.0
	51-60 years	22	22.0
	Above 60 years	10	10.0
Gender	Male	29	29.0
	Female	36	36.0
	Prefer not to say	35	35.0
Education Level	Primary/Middle School	29	29.0
	High School Certificate	11	11.0

Demographic Variable	Category	Frequency	Percentage (%)
	Technical Diploma/Certificate	24	24.0
	University Degree	26	26.0
	Other	10	10.0
Years Working in Ports/Shipping	Mean	-	3.10
	Standard Deviation	-	1.403
Where Do You Work	Sohar Port	100	100.0

Analysis of the 100 respondents from Sohar Port indicated that the surveyed workforce has varying age considerably proportions from 20-61 in varying domains of their careers. Among them. the largest segment is the biological professionals aged 20-30 years (29%) followed by the age group 51-60 years (22%) and 31-40 years (21%). Thus, the analysis is indicative of spreading and expansion of the 18% data of the age group 41-51 as well as the 10% retirement age veterans. out of which, there is sufficient evidence to form a conclusion that the populace consists of younger personnel and polished as well as experienced. This populace is inclusive enough to form versatile understanding pertaining to the management of waste and the sustainability projects in the maritime traditional versus modern approaches that are actively practiced as well operational and exposed in the field.

Gender-wise, the distribution is different and out of the total, 29 percent out which are male respondents, interestingly lower than the 36 percent of female respondents. This goes against the rule of thumb proportions of the males and females in the workforce in the maritime sectors. How about the 35 percent of the respondents who selected “other” in answer to the question on gender? This shows the gender-neutral approach the survey hoped to achieve. These are of the 29% of men and 36% of women who also contribute to the pool of respondents who constitute a fairly cohesive and supportive workforce at the Sohar Port.

The profile of the workforce describes people having knowledge capital sufficient to understand various aspects of the circular economy and lean manufacturing. While the number of people with primary and secondary school education was 29%, the proportion of vocational and university educated people was 50% (24% and 26% respectively) plus 11% was a high school graduate. This mix of education provided balance at multiple operational levels while ensuring sufficient technical knowledge for innovation in sustainability.

The number of years of professional experience on average was 3.10 (SD = 1.403) which suggested the presence of a workforce integrating institutional knowledge with novel ideas which is favourable for the deployment of creative models for waste reduction. The standard deviation suggested that there was true diversity in the level of experience whereby newcomers and old staff were provided with ample information on constraints and opportunities in the maritime operations of the Sohar Port across the various levels of experience.

Analysis of Survey Questions

Current Waste Streams and Inefficiencies

Table 2 Materials Reuse and Recycling Awareness

I often see materials being thrown away that could be reused or recycled in my work area					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Agree	54	54.0	54.0	54.0
	Strongly Agree	46	46.0	46.0	100.0
	Total	100	100.0	100.0	

It was noted by every respondent that there is considerable loss of materials which could in fact be reused or recycled. 54% confirmed and 46% strongly confirmed which underlined the fact that there is considerable awareness of waste and enormous potential for retrieval of materials in the operational environments.

Table 3 Impact of Equipment Breakdowns on Waste

Equipment breakdowns and maintenance delays cause waste of time and resources in my daily work					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Neutral/Not Sure	2	2.0	2.0	2.0
	Agree	58	58.0	58.0	60.0
	Strongly Agree	40	40.0	40.0	100.0
	Total	100	100.0	100.0	

More than half of the subjects of the survey and 40 percent strongly, 'waste time and resources' due to 'downtime' and 'maintenance.' Plus, 98 percent of the subjects accept this as a fact. This means only 2 percent were indifferent. This shows how widespread this thought is.

Table 4 Packaging Material Waste during Cargo Operations

We waste a lot of packaging materials (boxes, plastic, containers) during cargo operations					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Neutral/Not Sure	1	1.0	1.0	1.0
	Agree	47	47.0	47.0	48.0
	Strongly Agree	52	52.0	52.0	100.0
	Total	100	100.0	100.0	

Almost all respondents recognized significant waste of packaging materials, with 47% agreeing and 52% strongly agreeing. Only 1% were neutral, highlighting the ubiquitous presence of packaging waste and the need for targeted reduction strategies.

Table 5 Effect of Poor Coordination on Waste

Poor coordination between teams leads to unnecessary work and wasted effort					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Agree	59	59.0	59.0	59.0
	Strongly Agree	41	41.0	41.0	100.0
	Total	100	100.0	100.0	

Poor coordination between teams was identified as a major source of unnecessary work and wasted effort by all respondents, with 59% agreeing and 41% strongly agreeing. This emphasizes the importance of improving teamwork and communication to reduce waste.

Table 6 Resource Waste Awareness (Fuel, Water, Electricity)

I notice fuel, water, or electricity being wasted during work activities					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Agree	53	53.0	53.0	53.0
	Strongly Agree	47	47.0	47.0	100.0
	Total	100	100.0	100.0	

Respondents uniformly observed waste of fuel, water, or electricity during work activities, with 53% agreeing and 47% strongly agreeing. This highlights substantial opportunities for efficiency improvements in resource consumption.

Table 7 Support for Reuse and Recycling Programs

I would support programs to reuse and recycle materials instead of throwing them away					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Agree	55	55.0	55.0	55.0
	Strongly Agree	45	45.0	45.0	100.0
	Total	100	100.0	100.0	

100% of respondents either agreed (55%) or strongly agreed (45%) to support programs aimed at reusing and recycling materials instead of disposal, reflecting unanimous endorsement and readiness for sustainable material management practices within Sohar Port operations.

Table 8 Supervisor Encouragement for Waste Reduction

My supervisor encourages us to find ways to reduce waste and work more efficiently					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Neutral/Not Sure	1	1.0	1.0	1.0
	Agree	54	54.0	54.0	55.0
	Strongly Agree	45	45.0	45.0	100.0
	Total	100	100.0	100.0	

Nearly all respondents (99%) agreed (54%) or strongly agreed (45%) that supervisors encourage waste reduction and efficient work methods, with only 1% neutral. This indicates strong managerial support as a key driver for sustainable operations implementation.

Table 9 Effectiveness of Learning New Waste Methods

Learning new methods to reuse materials and eliminate waste would help me do my job better					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Agree	54	54.0	54.0	54.0
	Strongly Agree	46	46.0	46.0	100.0
	Total	100	100.0	100.0	

100% of respondents acknowledged that learning new methods to reuse materials would improve job performance, with 54% agreeing and 46% strongly agreeing. This underscores the perceived value of training and capacity building in waste minimization initiatives.

Table 10 Cross-Departmental Collaboration Benefits

Working together with other departments could help us reuse materials and reduce waste					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Agree	61	61.0	61.0	61.0
	Strongly Agree	39	39.0	39.0	100.0
	Total	100	100.0	100.0	

All respondents agreed that inter-departmental cooperation could enhance material reuse and waste reduction, with 61% agreeing and 39% strongly agreeing. This highlights collaboration as critical to sustainability success and circular economy implementation effectiveness.

Table 11 Belief in Faster and Cleaner Processes

I believe we can make our work processes faster and cleaner at the same time					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Neutral/Not Sure	1	1.0	1.0	1.0
	Agree	57	57.0	57.0	58.0
	Strongly Agree	42	42.0	42.0	100.0
	Total	100	100.0	100.0	

An overwhelming 99% agreed (57%) or strongly agreed (42%) that work processes can be simultaneously faster and cleaner, with only 1% neutral. This indicates strong optimism for efficiency gains aligned with environmental sustainability goals.

Economic and Environmental Impact

Table 12 Cost Savings through Waste Reduction

Reducing waste at work would help save money for the company					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Agree	55	55.0	55.0	55.0
	Strongly Agree	45	45.0	45.0	100.0
	Total	100	100.0	100.0	

All respondents agreed that reducing waste would save money for the company, with 55% agreeing and 45% strongly agreeing. This indicates clear recognition of economic benefits linked to sustainability initiatives and demonstrates unanimous understanding of the financial advantages of waste reduction strategies.

Table 13 Environmental Improvement from Efficient Resource Use

Using fewer materials and less energy would make our workplace better for the environment					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Agree	52	52.0	52.0	52.0
	Strongly Agree	48	48.0	48.0	100.0
	Total	100	100.0	100.0	

100% of respondents acknowledged that using fewer materials and less energy would improve the workplace environment, with 52% agreeing and 48% strongly agreeing. This underscores shared commitment to environmental sustainability and confirms awareness of resource efficiency's environmental benefits.

Table 14 Customer Preference for Sustainable Companies

Customers would prefer working with companies that care about reducing waste					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Agree	58	58.0	58.0	58.0
	Strongly Agree	42	42.0	42.0	100.0
	Total	100	100.0	100.0	

All respondents believed customers prefer companies that reduce waste, with 58% agreeing and 42% strongly agreeing. This highlights the perceived market advantage of sustainability practices and suggests recognition that environmental responsibility can enhance competitive positioning and customer relationships.

Table 15 Job Easiness through Waste Reduction and Efficiency

Reducing waste and working more efficiently would make our jobs easier					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Neutral/Not Sure	1	1.0	1.0	1.0
	Agree	53	53.0	53.0	54.0
	Strongly Agree	46	46.0	46.0	100.0
	Total	100	100.0	100.0	

99% agreed or strongly agreed that reducing waste and improving efficiency would make their jobs easier, with 53% agreeing and 46% strongly agreeing. Only 1% remained neutral, reflecting widespread optimism about operational improvements and personal benefits from sustainable practices.

Table 16 Community and Family Benefits from Pollution Reduction

My family and community would benefit if our workplace produced less pollution and waste					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Neutral/Not Sure	1	1.0	1.0	1.0
	Agree	52	52.0	52.0	53.0
	Strongly Agree	47	47.0	47.0	100.0
	Total	100	100.0	100.0	

All respondents agreed that less pollution and waste production at work would benefit their family and community, with 52% agreeing and 47% strongly agreeing. Only 1% were neutral, emphasizing the broader social impact and personal connection to environmental responsibility initiatives.

Table 17 Regular Waste Measurement Support

We should regularly measure and track how much waste we produce in our work area					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Agree	51	51.0	51.0	51.0
	Strongly Agree	49	49.0	49.0	100.0
	Total	100	100.0	100.0	

All respondents fully supported regular measurement and tracking of waste production, with 51% agreeing and 49% strongly agreeing. This unanimity underscores the perceived necessity of continuous monitoring as a foundation for zero-waste operations and effective performance management.

Table 18 Demand for Frequent Waste Reduction Reports

I would like to see daily or weekly reports showing our progress in reducing waste					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Agree	58	58.0	58.0	58.0
	Strongly Agree	42	42.0	42.0	100.0
	Total	100	100.0	100.0	

100% of respondents expressed strong interest in daily or weekly progress reports on waste reduction, with 58% agreeing and 42% strongly agreeing. This highlights the desire for transparent, timely feedback mechanisms to drive sustained improvement and accountability.

Table 19 Employee Recognition for Waste Reduction

Employees should be recognized or rewarded when they successfully reduce waste					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Neutral/Not Sure	1	1.0	1.0	1.0
	Agree	53	53.0	53.0	54.0
	Strongly Agree	46	46.0	46.0	100.0
	Total	100	100.0	100.0	

Nearly all respondents (99%) agreed that employees should be recognized or rewarded for successful waste reduction efforts, with 53% agreeing and 46% strongly agreeing. Only 1% remained neutral, emphasizing the importance of incentives and motivation in fostering a zero-waste culture.

Table 20 Need for Enhanced Material Monitoring Systems

We need better systems to monitor materials that get damaged or wasted					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Agree	55	55.0	55.0	55.0
	Strongly Agree	45	45.0	45.0	100.0
	Total	100	100.0	100.0	

All respondents supported the need for better systems to monitor damaged or wasted materials, with 55% agreeing and 45% strongly agreeing. This reflects acknowledgment of current technological gaps and the necessity for advanced tracking solutions to support zero-waste operations.

Table 21 Support for Regular Waste Reduction Meetings

New meetings to discuss the progress in waste reduction on a regular basis would help our team					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Agree	58	58.0	58.0	58.0
	Strongly Agree	42	42.0	42.0	100.0
	Total	100	100.0	100.0	

100% agreed that regular meetings to discuss progress in waste reduction would benefit the team, with 58% agreeing and 42% strongly agreeing. This reinforces the critical role of communication and collaboration in successful sustainability initiatives and continuous improvement processes.

Inferential Statistical Analyses

Table 22 Correlation Matrix of Main Research Variables

Variables	**1**	**2**	**3**	**4**
1. Current Waste Streams and Inefficiencies	1.000			
2. Integrating Circular Economy with Lean	.792**	1.000		
3. Economic and Environmental Impact	.745**	.821**	1.000	
4. Performance Measurement Tools	.678**	.732**	.837**	1.000

The correlation matrix revealed exceptionally strong and statistically significant relationships between all four research variables, providing compelling evidence for the interconnected nature of circular economy and lean manufacturing implementation in maritime supply chains. The strongest correlation emerged between current waste streams and inefficiencies and integrating circular economy with lean manufacturing practices ($r = .792$, $p < .01$), indicating that maritime professionals who perceived higher levels of operational

waste and inefficiencies demonstrated significantly greater readiness and motivation to adopt integrated circular-lean solutions. This finding supported the theoretical proposition that problem awareness serves as a critical catalyst for organizational change and sustainability transformation initiatives.

The relationship between integrating circular economy principles and economic and environmental impact showed an even stronger correlation ($r = .821$, $p < .01$), suggesting that individuals with higher integration readiness also held stronger beliefs about the potential benefits of circular-lean implementation. This robust association validated the research framework's emphasis on attitude-outcome linkages and demonstrated alignment between implementation willingness and expected value creation. Similarly, the very strong correlation between economic and environmental impact and performance measurement tools ($r = .837$, $p < .01$) indicated that respondents who anticipated greater benefits from circular-lean initiatives also strongly supported comprehensive measurement and monitoring systems, reflecting understanding of the critical role that performance tracking plays in achieving sustainability objectives.

The moderate to strong correlations between current waste streams and both economic impact ($r = .745$, $p < .01$) and performance measurement tools ($r = .678$, $p < .01$) further reinforced the systematic relationships underlying successful circular-lean transformation. These findings suggested that waste awareness not only drove integration motivation but also influenced perceptions of potential benefits and measurement system importance, creating a coherent framework for understanding implementation readiness across multiple dimensions of organizational change in maritime contexts.

Multiple Regression Analysis

Table 23 Model Summary

Model Summary	
R	.897
R Square	.804
Adjusted R Square	.798
Standard Error of Estimate	.16874
F-statistic	131.538***

Table 24 ANOVA

ANOVA	Sum of Squares	df	Mean Square	F	Sig.
Regression	11.236	3	3.745	131.538	.000
Residual	2.733	96	.028		
Total	13.970	99			

The multiple regression analysis results presented in Table 3 and Table 4 provide robust evidence about the predictive power of the studied variables on economic and environmental impact within the context of circular economy and lean manufacturing integration at Sohar Port. The model summary reveals an exceptionally high correlation coefficient (R = .897), indicating a strong linear relationship between the independent variables—current waste streams and inefficiencies, integration of circular economy principles with lean manufacturing, and performance measurement tools—and the dependent variable, which is the economic and environmental impact.

The R Square value of .804 demonstrates that approximately 80.4% of the variance in economic and environmental impact can be explained by the collective influence of the three predictor variables. This represents a very strong model fit, indicating that these factors comprehensively account for the majority of changes in perceived economic and environmental benefits resulting from circular-lean initiatives. The adjusted R Square of .798 further confirms the model's reliability by correcting for the number of predictors included, ensuring the robustness of the explanatory power without overfitting.

The standard error of estimate of .16874 suggests that the predictions made by the regression model are relatively precise, with a small average deviation between the observed values and those predicted by the model. The ANOVA table provides statistical significance for the regression model, with an F-statistic of 131.538 and a corresponding p-value less than .001 (Sig. = .000). This highly significant F-value indicates that the overall regression model is a good fit for the data and that the independent variables collectively have a statistically significant effect on economic and environmental impact.

The breakdown of sum of squares reveals that the regression model accounts for 11.236 units of explained variance, whereas the residual error variance remaining unexplained by the model is only 2.733 units. These values further support the strength and adequacy of the model in capturing the key drivers of

economic and environmental outcomes in Sohar Port's marine supply chains. Overall, the regression analysis confirms that current waste streams and inefficiencies, integration of circular economy and lean manufacturing practices, and performance measurement tools serve as significant predictors of economic and environmental impact, highlighting their importance in achieving sustainable maritime operations.

Thematic Analysis: Comparing Literature Review versus Survey Results per Objective

Objective 1: Current Waste Streams and Inefficiencies

Literature Review Themes

The literature review revealed that maritime operations have traditionally followed linear "extract-transform-throw" models, creating inherent waste streams across multiple operational areas. Key themes identified included systematic waste categorization encompassing galley operations, cargo handling activities, maintenance regimes, and administrative processes. The literature emphasized the need for material flow analysis to trace resource inputs and waste outputs, while highlighting operational inefficiencies stemming from poor coordination, equipment failures, and resource mismanagement. Theoretical frameworks suggested that waste awareness serves as a critical catalyst for organizational change toward sustainable practices.

Survey Results Validation

The empirical findings strongly corroborated literature predictions with remarkable consistency. Survey results demonstrated exceptional waste awareness among maritime professionals, with 98-100% of respondents acknowledging various waste streams. Specifically, material reuse opportunities received 100% agreement, packaging waste acknowledgment reached 99%, and resource waste recognition (fuel, water, electricity) achieved 100% consensus. The strong correlation between waste awareness and integration readiness ($r = .792$, $p < .01$) empirically validated the literature's theoretical proposition that problem recognition drives change motivation.

Thematic Convergence

The alignment between literature predictions and empirical findings was striking. Both sources identified equipment breakdowns (98% survey agreement vs. literature emphasis on maintenance inefficiencies), coordination problems (100% survey agreement vs. literature focus on cross-functional challenges), and material waste (100% survey agreement vs. literature's circular economy potential) as primary concerns. This convergence strengthens confidence in the theoretical framework's applicability to real-world maritime contexts.

Objective 2: Integration Framework Development

Literature Review Themes

The literature revealed significant knowledge gaps in integrated circular-lean applications within maritime contexts, particularly in emerging markets. Key themes included stakeholder cooperation challenges, the need for multi-actor arrangements transcending traditional port authority boundaries, and competing imperatives between lean's efficiency focus and circular economy's resource retention goals. The literature emphasized organizational readiness and cultural factors as critical success determinants, while noting the complexity of integration frameworks requiring specialized governance structures.

Survey Results Contradiction and Validation

Surprisingly, the survey results revealed much higher readiness levels than literature suggested possible. While literature indicated significant implementation challenges, 99-100% of respondents expressed strong support for integration initiatives. Supervisory encouragement received 99% agreement, cross-departmental collaboration achieved 100% support, and learning new methods gained unanimous endorsement. The exceptionally strong correlation between integration readiness and expected impacts ($r = .821$, $p < .01$) suggested that attitude-outcome linkages were more robust than literature indicated.

Thematic Divergence and Insights

The most significant finding was the divergence between literature pessimism and empirical optimism. While literature emphasized barriers and challenges, survey respondents demonstrated remarkable change readiness and collaborative attitudes. This suggests that Sohar Port's organizational culture may be more conducive to transformation than typical maritime organizations studied in existing literature.

Objective 3: Economic and Environmental Impact Assessment

Literature Review Themes

Different strands of literature have developed impact frameworks demonstrating direct and indirect effects for multiple stakeholders across various time periods. Please summarise and define themes around waste valorisation cost savings mechanisms, material recovery revenues, infrastructure spending for economic development, and ecosystem benefits beyond operational enhancements.

Survey Results Alignment

The benefits derived from the recognition aligned with gaining customer preference benefits acknowledgment as well as the economy with the one hundred percent supported thousand percent agreement to environmental improvements. These results exposed a far wider agreement than anticipated and augmented the literature models with the pragmatic results. The survey revealed perfect alignment between dual value creation expectations (economic and environmental) with 99-100% agreement across all impact dimensions.

Notably, the community benefit recognition (99% agreement) confirmed literature predictions about broader social value creation.

Thematic Synthesis

The convergence between literature predictions and empirical validation was comprehensive. Both sources confirmed win-win sustainability outcomes, stakeholder value creation, and competitive advantage potential. The survey results provided empirical validation for literature's theoretical assertion that circular-lean systems can simultaneously deliver financial performance and environmental stewardship. The strong regression model ($R^2 = .804$) confirmed literature's emphasis on integrated impact assessment approaches.

Objective 4: Performance Measurement Tools Development

Literature Review Themes

The literature emphasized the critical role of measurement systems in enabling circular-lean transformation while highlighting framework underdevelopment in maritime contexts. Key themes included the need for integrated metrics balancing operational and environmental indicators, digital technology enablement through IoT sensors and analytics platforms, real-time monitoring capabilities, and comprehensive performance dashboards. The literature noted limited attention to measurement frameworks specifically designed for maritime circular-lean systems.

Survey Results Validation and Extension

The survey results provided overwhelming validation of literature themes while revealing even stronger measurement appetite than anticipated. Implementation of regular waste measurement was met with 100 percent support, achieving 100 percent agreement on progress reporting and, also, employee recognition systems gained 99 percent endorsement. The measurement-impact correlation also supports very strongly the literature prediction about measurement-impact relationships with ($r = .837$, $p < .01$).

Thematic Innovation

The survey results extended literature themes by revealing unprecedented measurement enthusiasm among maritime professionals. While literature suggested measurement systems were underdeveloped, survey respondents demonstrated sophisticated understanding of performance tracking necessity and feedback loop importance. The unanimous support for monitoring systems (100% agreement) suggests that measurement culture may be more advanced in practice than literature indicates, particularly in progressive port environments like Sohar.

Cross-Objective Thematic Synthesis

Overarching Convergence Patterns

Across all four objectives, several meta-themes emerged from the literature-survey comparison. First, theoretical frameworks consistently predicted empirical patterns, validating the research's conceptual foundation. Second, survey results exceeded literature expectations in terms of readiness and enthusiasm levels, suggesting that emerging market maritime contexts may offer unique transformation opportunities. Third, correlation patterns confirmed theoretical relationships while revealing stronger associations than literature suggested possible.

Cultural and Contextual Insights

From the analysis, it appears that the culture within Sohar Port is, on the whole, conducive to sustainable change. Whether the individuals who answered the survey possessed as much “readiness for change” as was postulated is arguable, given that the literature predominantly concerned itself with barriers to implementation. This brings to mind the idea that the maritime sector in the Middle East possesses specific characteristics that are beneficial for implementing circular-lean systems, such as a strong sense of collectivism, sustainability thinking at the organizational level, and enabling systems at the institutional level.

Framework Validation and Extension

As opposed to what was captured in the literature review and confirmed later during thematic analysis, the integrated circular lean framework was found contextually practical and theoretically defensible. Literature often focuses on the collection of implementation success factors. In constructing the literature review and the survey data, this approach seems to be more positively aligned from an implementation success factor viewpoint concerning stakeholder readiness, measurement appetite, and the anticipated impact. In this case, the survey results advance the literature framework. They demonstrate, in this instance and from the survey results, the contextual elements matter in determining the shift potential.

Research Contribution Implications

While previous works (circular economy, lean manufacturing, maritime operations) have been studied individually, their simultaneous application to emerging market contexts still offers novel insights. This expands the theoretical understanding of the global transformation dynamics for sustainability to the maritime supply chains and also offers the first empirical evidence on the feasibility of circular-lean integrations within emerging market contexts like Oman’s Vision 2040 framework.

Chapter Summary

The chapter described the quantitative research design that utilizes the surveys of 100 maritime professionals in Sohar Port. It described purposive methods of sampling, construction of questionnaires, testing of validity and reliability (Cronbach α = 0.836) and statistical analysis procedures. The methodology guaranteed ethicality as it recorded different views at various levels and departments of operation.

V. DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

Introduction

In this chapter, the researcher elaborates on the findings of the study, in particular, the quantitative analysis based on the data made available from the surveys of 100 maritime practitioners working at Sohar Port. Researcher also explains the results from the study of the application of the principles of the circular economy to the lean construction of marine supply chains and the consequent possibilities of reducing waste and improving efficiency in maritime activities. This part of the thesis is structured around the four major objectives of this research. For each, researcher elaborate the findings, formulate conclusions and suggestions on what should be done next from the point of view of evidence-based practice.

Summary of Findings per Objective

Objective 1: Current Waste Streams and Inefficiencies

The study conducted on the waste streams as well as inefficiencies at Sohar Port was focused on in-depth understanding of the distinct operational areas of waste management across all functionality boundaries. The outcome of the study showed that all maritime professionals had in-depth comprehension of the inefficiencies that characterized their day-to-day activities and there was significant consensus as to the waste kinds and the effects of their presence.

The respondents to the study all categorized material inefficiencies as the most common type of waste whereby 100% of respondents agreed that it was possible to reuse and recycle all the materials that were routinely discarded, and thus there was a positive correlation to the value principle of the circular economy. This circular economy value principle shown was the rejuvenation of the lost value into an economic cyclic flow, which the respondents successfully mapped. The fact that the rejected material waste potential was all unanimously recognized indicates that a ‘value cycle’ could be established without the necessity of an awareness building campaign at any organizational level.

The respondents in our study also came to a consensus that there were equipment-related inefficiencies which 98% of the participants agreed that breakdowns and maintenance delays, in particular, wasted a large amount of time and resources. This also showed the interrelation between operational efficiency and waste, whereby maintenance could serve as an optimum to productivity waste, and thus operational waste as a whole.

Respondents' claims that 99% of respondents viewed the excessive cargo packing as a waste of materials in container handling and freight management waste stream strengthened the rational for developing packaging that enhances container reusability, and improved collaboration between cargo packers and cargo wrapper.

With which together, the depreciation of the costly and scarce resources which stands as waste of the fuels and utilities, the appreciation of which is at 100%. Alongside the efforts with the energy management systems, the monitoring of waste and consumption, the minimization of operational costs, and system performance enhancement silos could be lowered in an operationally holistic manner.

Objective 2: Integration Framework Development

The results indicated that those in the maritime field not only grasp the idea of various approaches to sustainability being integrated, but also support their active implementation.

There were 100% agreement with support of reuse and recycling programs, where 55% agreed and 45% strongly agreed to take part in materials recovery programs. This overwhelming consent suggests that the so-called change resistance and often regarded as the primary barrier to the implementation of sustainability principles, may not be of much concern at the Sohar Port. This finding indicated that organizational culture, at the very least, is supportive of environmentally sustainable and resource use being at a minimum. (Salman et al, 2024).

The support for, and the encouragement of, the waste reduction and the increased efficiency improvements was appreciated by 99% of the respondents, suggesting stronger environmental objective principles to be the focus of the management. This found that the support of the so-called 'leadership' in the literature, being regarded as a critical success factor is already found at the Sohar Port. The offered support of the management suggests that the advocacy would be in favour of the initiatives in advocacy suggesting that the change management that would be needed, would be of a very small scale (Hartini, 2025).

All respondents achieving a 100% agreement level on learning orientation toward new methods to reduce waste signified remarkable willingness to undergo training and accept new concepts. This result suggested that there would enthusiastic acceptance of training and development programs on circular economy and lean manufacturing techniques. The lack of resistance to learning suggested that the organization would undertake training investments expecting training to be quickly implemented and new concepts embraced.

All respondents achieving a 100% agreement level on the potential to collaborate across departments signifies the recognition that the nature of change the organization is going through requires more than one discipline to work together (Yang et al., 2022). This result suggested that focused approaches to achieving sustainability would be inadequate, whereas approaches that address sustainability through the collaboration

of various departments would be embraced. This recognition of the need for collaboration proofed the organization's capability to manage complex change aligned with the maturity of the organization.

All respondents demonstrating agreement with 99% on process improvement supplement the hypothesis that work processes can be completed faster and, at the same time, done in a cleaner way. This result supported the hypothesis that capturing greater levels of efficiency, at the same time, captures better levels of positive environmental impact is a non-competing situation. The strong agreement that the circular lean approaches will work confirms the perception that integrated approaches will work. The conclusion can be advanced that integrated circular-lean approaches will be perceived as win-win rather than trade-off scenarios (Dey et al., 2022).

Objective 3: Economic and Environmental Impact Assessment

The examination of perceived economic and environmental impacts revealed strong consensus regarding the dual benefits of circular-lean implementation. The findings demonstrated that maritime professionals understand sustainability initiatives as value-creating investments rather than cost-imposing requirements

Economic benefits through waste reduction received 100% agreement, indicating universal recognition that sustainability initiatives can improve financial performance. This finding suggested that business case development for circular-lean projects would face minimal scepticism, as the workforce already understands the cost reduction potential. The unanimous agreement on economic benefits indicated that financial justifications for sustainability investments would resonate strongly with stakeholders (Nujen, 2023).

Environmental improvements through resource efficiency were acknowledged by 100% of respondents, demonstrating comprehensive understanding of ecological benefits. This finding indicated that environmental stewardship motivations are well-established, suggesting that sustainability communications should emphasize both economic and environmental value propositions. The universal recognition of environmental benefits suggested that corporate social responsibility initiatives would receive enthusiastic workforce support (Nujen, 2023).

Customer preference advantages were recognized by 100% of respondents, indicating awareness that sustainability practices can enhance competitive positioning. This finding suggested that market-driven motivations for circular-lean implementation would be well-understood and supported by the workforce. The recognition of customer benefits indicated that external stakeholder value creation is appreciated alongside internal operational improvements.

Job satisfaction improvements were acknowledged by 99% of respondents, demonstrating understanding that waste reduction and efficiency gains can enhance work experiences. This finding suggested that sustainability initiatives would be perceived as employee benefit programs rather than

additional work requirements. The strong agreement on job improvement potential indicated that workforce engagement in circular-lean implementation would be self-reinforcing.

Community and family benefits were recognized by 99% of respondents, indicating understanding that workplace sustainability initiatives create broader social value. This finding suggested that corporate citizenship motivations would resonate strongly with the workforce, supporting community engagement and social responsibility programs. The recognition of community benefits indicated that sustainability initiatives would be perceived as contributing to societal well-being beyond organizational boundaries.

Objective 4: Performance Measurement Tools Development

The investigation into performance measurement preferences revealed exceptional support for comprehensive monitoring and evaluation systems. The findings demonstrated that maritime professionals recognize measurement as essential for successful circular-lean implementation and are eager to participate in data-driven improvement processes.

Regular waste measurement and tracking received 100% support, indicating unanimous recognition that continuous monitoring is fundamental to waste reduction success. This finding suggested that measurement system implementation would encounter no resistance while receiving active cooperation from operational personnel. The universal support for tracking indicated that data collection and reporting processes would be viewed as valuable management tools rather than administrative burdens.

Conclusions per Objective

Objective 1: Current Waste Streams and Inefficiencies

The research conclusively demonstrates that Sohar Port faces significant waste challenges across multiple operational dimensions, but these challenges are comprehensively understood by the workforce and represent substantial opportunities for improvement. The universal recognition of waste issues indicates that problem awareness, often the first barrier to organizational change, has been overcome. This conclusion suggests that Sohar Port is uniquely positioned to implement circular economy solutions because the foundational requirement of waste awareness is already established (Draxler et al., 2020).

The systematic nature of waste recognition across material, equipment, coordination, and resource categories indicates that integrated solutions addressing multiple waste streams simultaneously would be most effective. Focusing on a singular operational waste stream in isolation runs the risk of losing far more substantial opportunities addressed through a holistic view toward operational inefficiencies (Draxler et al., 2020).

Objective 2: Integration Framework Development

It is clear that Sohar Port is more than ready on an organizational level to combine circular economy and lean manufacturing principles. The almost complete support for all integration dimensions is an indication

that cultural and attitudinal resistance to change is minimal. In organizational change situations, this is the opposite of what is typically the case, where resistance to change is the principal obstacle to implementation (Nowicki et al., 2023).

Having supervisory support, or support at higher levels of the organization, provides a strong basis for implementation of the identified 'sustainability framework'. The conclusion reached here is that change management initiatives should be designed to build capabilities, and allocate the appropriate resources, rather than construct initiatives aimed to develop motivation and organizational buy-in to the new proposed realities.

The strong support for collaboration and learning is a positive indication that the employees possess the requisite characteristics to successfully engender change. This implies that Sohar Port is able to implement advanced circular-lean programs without the long delays typically needed to develop organizational readiness.

The processes which are able to guarantee that an organization becomes faster and at the same time cleaner and greener, showcase the pre-existing conditions under which efficiency and sustainability are no longer competing objectives but are instead complementary to each other. This provides support for the need to implement integrated approaches instead of delaying implementation of circular and lean initiatives, or treating them separately (Skalli, 2024).

The study says that the integration frame development should focus more on practical tools and technical abilities instead of on change management and resistance. The exceptionally high levels of preparedness suggest that the conventional obstacles to transformative change sustainability may not apply to advanced maritime institutions that have robust environmental protection awareness and a commitment to leadership.

Objective 3: Economic and Environmental Impact Assessment

The professionals of the maritime industry stationed at Sohar port, in particular, have conceptualized the implementation of circular-lean to integrate value creation activities across the economic, environmental, social and above all operational activities at the same time. This is the reason why the dual benefits of the sustainability initiatives will be viewed positively and regarded as investments rather than costs (Skalli, 2024).

The absence of doubt and disagreement on economic payoffs supporting the reasoning of circular-lean projects creates a condition where the financial rationales of such projects will be attractive at best. Given the active backing from the workforce, and strong support the finding suggests, scepticism will be absent. This finding is particularly important because it addresses the roadblocks to closure which rest on the inhibition premise of restrictive organizational economic viability perception.

The lack of discord on the value of benefits that stem from the environmental sustainability initiatives suggests that the advocacy for pro-ecological motives is strong and can be used for the purpose of implementation. In addition to the economic instrumental shape, this environmental awareness constitutes a

strong reason, making the case for the pro-eco-advocacy, which drives the circular-lean approach (Skalli, 2024).

The recognition of customer and community benefits concludes that stakeholder value creation is understood and appreciated by the workforce. This awareness supports market positioning and corporate citizenship strategies that leverage sustainability practices for competitive advantage and social responsibility.

The research concludes that impact assessment frameworks should emphasize multiple value dimensions rather than focusing exclusively on financial returns. The comprehensive benefit recognition indicates that integrated value propositions addressing economic, environmental, and social outcomes will resonate most strongly with stakeholders and sustain long-term commitment to circular-lean practices.

Objective 4: Performance Measurement Tools Development

The research conclusively establishes that maritime professionals at Sohar Port recognize performance measurement as essential for circular-lean success and are eager to participate in comprehensive monitoring and evaluation systems. The universal support for measurement initiatives indicates that data-driven management approaches will be welcomed rather than resisted.

The desire for frequent progress reporting concludes that transparent communication and accountability systems will enhance motivation and engagement rather than creating additional administrative burden. This finding supports real-time dashboard development and regular performance communication as motivational tools.

The strong support for recognition systems concludes that incentive programs can effectively reinforce desired behaviours and celebrate achievements. This recognition indicates that performance-based reward systems will be viewed as fair and motivating, supporting their implementation as change management tools.

Recommendations

Based on the research findings demonstrating exceptional organizational readiness and strong empirical relationships between circular economy integration and operational outcomes, four key recommendations emerge for Sohar Port's sustainable transformation.

First, implement integrated waste management systems addressing multiple waste streams simultaneously. The research revealed universal recognition of material waste (100% agreement), packaging inefficiencies (99% agreement), and resource waste (100% agreement). Instead of snapshots of waste minimization interventions, Sohar Port should embrace holistic strategies that include material flow analysis, digital geo-tracking, and interdepartmental coordination fusion teams. This leverages the strong affinity between lack of waste awareness and waste integration readiness ($r = .792$) and addresses the coordination issues identified by all respondents (Skalli, 2024).

Second, establish circular-lean excellence centres that capitalize on overriding support for learning new methods (100%-level agreement) and interdepartmental collaboration (100%-level agreement). To strengthen an organization's ability and sustain improving momentum, such centres should provide design and instructional materials, innovation lab resources, and organizational learning systems.

Successful achievement comes with the adoption of advanced performance systems, owing to the universal expressed need to continually track and report progress on waste (100% agreement). Dashboards and other monitoring and recognition systems enable real-time engagement and accountability, which is central to the desired long-term outcome.

Strategic partnerships need to be established with other technology, waste processors, and the entire supply chain. Recognition of the customers' inclination to continue to sustain such sustainable companies reveals new, more attainable market possibilities made easier with such partnerships, especially in extending circular principles beyond the port.

Future Research Opportunities

Sohar Port may be more prepared than the literature suggests. This disconnect shows important new areas for further exploration (Skalli, 2024). Future studies examining the longitudinal effects of circular-lean systems and assess the implementation of the systems over extended periods to gauge actual sustained performance improvement against the strong expectations set out in this research, which remains a gap in the literature. The research suggests a significant gap in understanding the delayed gratification phenomena in the implementation of circular-lean systems sustained enduring success. The 80.4% of variance in the expected impacts captured and explained by the aggregate regression model serves as a guiding benchmark to assess real-world outcomes and recalibrate enduring success strategies and sustained success management elements.

Understanding the emphasis placed on the unique contextual factors facilitating such exceptional change preparedness, especially in the context of emerging market maritime and the unique spatial, cultural and operational contexts, would add value to the literature on Comparative multi-port studies. The differentiated levels of technological preparedness in supporting the concept of circular-lean systems to emerging technologies remains a gap in the literature on circular economy research. The outcomes point out the implementation gaps of technological solutions as the enhanced monitoring systems are commonly supported by circular-lean operations. The significant support for enhanced monitoring systems which attained the highest level of agreement (100%) indicates the need reinforced technological solutions but warrants further research on the specific systems configurations and implementation frameworks.

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