

Analyzing Success Factors and Barriers to Spare Parts Sustainability in Lean JIT Systems: An AHP-Based Study in the Military Sector

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Abstract

This study explores how Lean and JIT practices advance Sustainable Development Goal 12 (Responsible Consumption and Production), which aims to ensure sustainable consumption and production patterns to protect the planet and promote resource efficiency within spare parts management, specifically in defense logistics. Through using a quantitative survey method and multiple regression analysis of 30 Ministry of Defense professionals, the research identifies the key drivers and barriers to sustainable operations. Results show that leadership, TPM, and employee involvement significantly boost sustainability performance. However, unpredictable demand and limited digital integration remain the most significant challenges to achieving a fully optimized, waste-free supply chain.

Keywords

Supply Chain Management, Lean, Just In Time, Spare Part Management, Defense Logistics.

1. Introduction

This paper focuses on the intersection of Lean/JIT methodologies and the United Nations Sustainable Development Goals (SDG 12). Spare parts management, particularly in the defense sector, often faces challenges of overstocking or stock-outs. By applying Lean principles, organizations can minimize waste and optimize resource efficiency. The primary objectives of this study are as follows:

- To examine how Lean and Just-In-Time (JIT) spare parts management practices contribute to achieving Sustainable Development Goal 12, with a focus on reducing waste, improving resource utilization, and promoting responsible production and consumption.
- To identify and analyze the critical success factors (CSFs) — such as leadership commitment, employee involvement, and digital integration — that enable effective implementation of Lean and JIT systems in spare parts logistics.
- To explore and address the major barriers — including demand unpredictability, organizational resistance, and supplier limitations — that hinder the integration of Lean and JIT approaches within sustainable spare parts management.

- By fulfilling these objectives, the research aims to contribute to the theoretical understanding of Lean/JIT–sustainability linkages and to provide practical recommendations for improving operational efficiency in public sector logistics, particularly within the defense context of Qatar.

The primary objectives of this study are to examine how Lean and Just-In-Time (JIT) spare parts management practices contribute to achieving Sustainable Development Goal 12, particularly by reducing waste, improving resource utilization, and promoting responsible production and consumption. The study also aims to identify and analyze the critical success factors, such as leadership commitment, employee involvement, and digital integration, that enable the effective implementation of Lean and JIT systems in spare parts logistics. In addition, the research seeks to explore and address the major barriers, including demand unpredictability, organizational resistance, and supplier limitations, that hinder the integration of Lean and JIT approaches within sustainable spare parts management.

2. Literature Review

2.1 Introduction

The purpose of this chapter is to critically review the existing literature related to Lean Management, Just-In-Time (JIT) practices, and their connection to Sustainable Development Goal 12 (Responsible Consumption and Production). It establishes the theoretical foundations, identifies prior research contributions, and highlights the gaps that this study aims to address.

Lean and JIT approaches have evolved beyond manufacturing contexts to influence sustainability and supply chain performance (Almeida et al., 2024). This chapter, therefore, explores how these methodologies contribute to efficient resource utilization, waste reduction, and sustainable logistics — with a focus on spare parts management in the defense sector.

2.2 Lean Methodology and Environmental Sustainability

Lean Management is a systematic approach that aims to eliminate non-value-adding activities, enhance process efficiency, and deliver maximum customer value using minimal resources (Womack & Jones, 2020). The “Lean” philosophy originated from the Toyota Production System, emphasizing continuous improvement (Kaizen), employee empowerment, and waste minimization.

Recent studies show that Lean practices are increasingly recognized as enablers of sustainability (Garza-Reyes, 2023). Lean tools such as 5S, Value Stream Mapping (VSM), and Kaizen contribute directly to environmental performance by reducing material usage, energy consumption, and emissions (Kumar & Rajesh, 2024).

Moreover, the social dimension of sustainability is enhanced through workforce involvement and skill development (Feng et al., 2023). In Qatar and the Gulf region, Lean initiatives have been integrated with digital technologies such as IoT and AI-driven predictive maintenance to improve sustainability performance (Al-Sulaiti & Thomas, 2025). This demonstrates that Lean not only reduces costs but also promotes long-term environmental stewardship, aligning with SDG 12 objectives.

2.3 Inventory Optimization and Just-in-Time

Just-In-Time (JIT) is a production and inventory strategy that seeks to deliver materials precisely when they are needed, thereby minimizing waste, reducing inventory costs, and enhancing responsiveness (Ohno, 2019).

While JIT is traditionally associated with operational efficiency, recent literature emphasizes its sustainability potential. JIT reduces overproduction and storage energy consumption, supporting responsible resource utilization (Singh & Gupta, 2023).

According to Li et al. (2024), integrating JIT with digital supply chain systems leads to reduced carbon footprints and improved environmental compliance. However, researchers also caution that excessive reliance on JIT without supply chain resilience can increase risk exposure, particularly during disruptions such as the COVID-19 pandemic (Ivanov, 2023).

Thus, modern JIT approaches increasingly combine resilience-oriented planning and green logistics principles, ensuring sustainability without compromising reliability.

2.4 Benefits of Using Lean and JIT

The combination of Lean and JIT in the process of managing spare parts can bring many sustainability and operational benefits. Value stream mapping (VSM), 5S, Kaizen, and total productive maintenance (TPM) are lean tools helping organizations to synchronize their logistics operations and cut down wastes and optimize resource use (Pdr & Lanka, 2025). Combined with the demand-based philosophy of JIT, such tools allow cutting down the unnecessary inventory, reducing obsolete on-hand inventory, and enhancing the efficiency of stock rotation (Shah & Ward, 2007; Chiarini, 2013).

JIT responsiveness enhances continuity within the production process, which creates fewer delays and more imagined Zwischenhaltzeiten. According to the research of Ahuja and Khamba (2008), the availability of critical parts could be achieved through the integration of Lean and JIT, combined with lessening production costs in the lifecycle. This advantage is more evident in heavily capitalized industries such as manufacturing, logistics, and energy, where the performance of equipment is a critical feature that determines the sustainability of operations. The improvement of lead times and less downtime of machines has direct input to SDG 12 and SDG 9 (the support of innovation and infrastructure resilience) (Womack & Jones, 1996).

In addition, Lean systems and JIT help in larger strategic objectives, including customer satisfaction and speed. Organisations that embrace the practices report improved service delivery and quick response to the changing needs (Susanty et al., 2021). Therefore, Lean and JIT advantages in operations are not only within companies, but outside the company too, and where the company can develop a competitive edge in the global supply chains.

2.5 Enablers of Lean and JIT Implementation

Critical success factors (CSFs) play a vital role in determining the successful integration of Lean and JIT in spare parts logistics. Netland (2015) highlights that top management support is one of the most important enablers. Leadership is required to align Lean and JIT efforts with organizational goals, provide strategic direction, and allocate necessary resources (Fullerton & Wempe, 2009). Strong leadership commitment ensures that change initiatives are sustained, especially in the face of internal resistance or uncertainty.

Employee engagement is another key enabler. Bhasin (2012) states that Lean transformations are more successful when employees at all organizational levels are trained in Lean tools and encouraged to participate in identifying and eliminating waste. The concept of kaizen fosters a culture of continuous improvement, promoting ownership and accountability among staff (Digital Twin Empowering Manufacturing Paradigms, 2023).

Training and communication further enhance employee empowerment. Organizations that invest in structured Lean training programs build stronger internal capabilities and reduce dependency on external consultants (Alkhoraf, Rashid & McLaughlin, 2019). Encouraging cross-functional collaboration between maintenance, procurement, and supply chain teams also enhances process integration and knowledge sharing.

2.6 Supplier Collaboration and Digital Infrastructure

For JIT systems to function effectively, regular collaboration with reliable suppliers is essential. Kannan and Tan (2005) highlight that trust, shared data platforms, and joint planning significantly contribute to achieving supply chain synchronization. Alignment leads to improved lead times and improved inventory control. Techniques that decrease lead times and improve inventory control include vendor-managed inventory, supplier co-location, and quality assurance.

Digital technologies are important to facilitate this collaboration. Gunasekaran, Subramanian, and Papadopoulos (2017) maintain that the use of such technologies as a cloud-based ERP system, a real-time communication platform, and electronic data exchange (EDI) tools can greatly enhance the visibility of the supply chain. Regarding international activities, the systems eliminate the time zones and geographical distance and make the coordination of JIT deliveries easier.

Moreover, by implementing the technologies of the industry, organizations can predict their spare parts requirements and trigger commissions to restock them in a timely manner (Bag, Gupta & Kumar, 2020). This minimizes unexpected shutdowns, and it agrees with the philosophy of the JIT, which is the reduction of waste and the right part at the right time.

2.7 Barriers to Implementation

Despite the many advantages, several barriers hinder the effective implementation of Lean and JIT in spare parts logistics. One of the most prominent challenges is the unpredictability of demand. Spare parts frequently have intermittent or highly variable demand patterns, which makes traditional forecasting methods unreliable (Croston, 1972). As a result, many organizations overstock spare parts as a buffer, a practice that runs counter to the core principles of JIT.

Resistance to change is another well-documented challenge. Employees, particularly those in warehouse and maintenance roles, may view Lean and JIT practices as cost-cutting measures rather than strategic tools for improvement (Maware & Parsley, 2022). Bhasin (2012) found that a lack of understanding, fear of job loss, and insufficient training contribute to this resistance. Overcoming such barriers requires open communication, participatory planning, and demonstrated success to build trust.

External disruptions, such as the COVID-19 pandemic, further complicate the application of Lean and JIT. Ivanov and Dolgui (2020) illustrate how JIT-based global supply chains were severely impacted during the pandemic, prompting a shift toward more resilient supply chain models. To mitigate such risks, organizations are increasingly adopting hybrid or "Leagile" models that blend Lean efficiency with strategic inventory buffers and risk mitigation plans.

2.8 Role of Digital Technologies and Circular Economy

Digital technology is used as a stimulator and a remedy in solving the above barriers. Machine learning and big data help in predictive analytics that boost the precision of the anticipated parts with irregular demand (Tiwari, Wee & Daryanto, 2018). Such technologies assist in more sophisticated inventory replenishment plans, detect possible disruptions beforehand, and make condition-based maintenance possible.

With the help of digital tools, it is possible to know about the equipment state in real-time, which means that replacement of parts can be done exactly when it is necessary, without ever wasting them and increasing uptime (Bag, Gupta & Kumar, 2020). This is enhanced by the use of artificial intelligence (AI) that helps in the identification of consumption trends, recommendation of reorder level, and improvement of the system's responsiveness (Walk et al., 2023).

Circular Economy (CE) provides an additional approach toward greater sustainability of the logistics of spare parts. Remanufacturing, reuse, and recycling are CE principles that are related to Lean since the latter is focused on reducing waste (Nohra, Ben Rejeb & Venkateswaran, 2022). Using remanufactured components helped limit environmental waste as well as help meet SDG 12 goals. According to Xing et al. (2010), remanufacturing may cut down on the lifecycle emissions by a possible 70 percent.

Nonetheless, issues about implementing CE in practice exist. Irregularities in regulations, the quality of products, or the absence of a reverse logistics framework limit mass adoption (Alkhoraif, Rashid & McLaughlin, 2019). To counteract these, organizations should invest in traceability systems, warranties of remanufactured goods, and customer participation incentives.

To conclude, although Lean and JIT offer effective solutions in enhancing spare parts logistics and sustainability objectives, their use is not without any inherent problems. A moderate approach using the combination of digital innovation, employee engagement, robust leadership, and the practices of the circular economy is required to uncover their entire potential.

2.9 Research Gaps and Future Research Directions

Despite the growing body of literature surrounding Lean and Just-In-Time (JIT) practices in spare parts management, several research gaps persist. Firstly, while numerous studies affirm the operational and environmental benefits of Lean and JIT systems, there is limited empirical research directly linking these practices to measurable sustainability outcomes, particularly those aligned with specific Sustainable Development Goals such as SDG 12 (United Nations, 2015). Most existing studies emphasize theoretical or case-specific benefits without quantifying their broader sustainability impact in diverse industry settings (ResearchGate, 2025).

Secondly, the application of Lean and JIT in spare parts logistics has been primarily explored in manufacturing-centric or large-scale industrial environments, such as automotive and aerospace (Antoniadou, 2024; DE et al., 2022). However, smaller firms, healthcare systems, or public sector organizations remain underrepresented in current research, despite having critical spare parts needs. This limits the generalisability of best practices and creates a skewed understanding of implementation barriers and enablers across sectors.

Furthermore, digital transformation technologies—such as IoT, big data, artificial intelligence (AI), and blockchain—have been acknowledged as enablers in optimizing Lean and JIT practices (Bag, Gupta & Kumar, 2020; Walk et al., 2023). However, there is still limited empirical work exploring how these technologies can be practically deployed in spare parts logistics to enhance forecasting accuracy, visibility, and responsiveness. Future research should explore the scalability and cost-effectiveness of digital interventions, especially for small and medium-sized enterprises (SMEs).

There is also a scarcity of longitudinal studies examining the long-term impact of Lean and JIT implementation on sustainability outcomes. Most available literature focuses on short-term efficiencies or operational improvements without evaluating how these systems evolve over time or adapt during crises such as the COVID-19 pandemic (Ivanov & Dolgui, 2020). Investigating the resilience and adaptability of Lean/JIT systems under disruption can provide insights for building more robust and flexible supply chains.

Finally, the human dimension—particularly employee perceptions, behavioral resistance, and change management in Lean and JIT transitions—deserves more attention (Bhasin, 2012; Maware & Parsley, 2022). Quantitative research exploring the social dynamics and cultural factors that influence adoption and resistance would complement quantitative performance metrics and help create holistic implementation strategies.

In light of these gaps, future research should focus on:

- Developing sector-specific models for Lean/JIT adoption in underexplored industries.
- Integrating CE principles within Lean and JIT frameworks.
- Investigating digital transformation's real-world applications and limitations.
- Conducting longitudinal and cross-regional studies for comparative insights.
- Exploring employee-level behavioral and cultural factors during implementation.

Addressing these directions enhances the theoretical understanding and provide practical guidance for industries seeking to align operational performance with sustainable development objectives.

2.10 Research Model/ or Research Question

A focused research model was developed to discuss the existing gaps in the current body of literature and be clear on the relevance of Lean and Just-in-Time (JIT) practices as drivers of sustainability in spare parts management. The chapter contains such details as the conceptual model and three research questions, which form the basis of data collection and analysis (See Figure 1).

- How do Lean and Just-in-Time (JIT) spare parts management practices contribute to achieving Sustainable Development Goal 12 (Responsible Consumption and Production)?
- What are the critical success factors and barriers that influence the effective implementation of Lean and JIT practices in spare parts management?
- How can digital technologies and hybrid approaches (such as Leagile models) enhance the sustainability outcomes of Lean and JIT spare parts management?

Considering the research model and the objectives of the study, the following research questions are raised:

- How do Lean and JIT spare parts management practices contribute to achieving Sustainable Development Goal 12, particularly in minimizing waste and promoting efficient resource use?
- What are the critical success factors that enable the effective integration of Lean and JIT practices in spare parts logistics and supply chain management?
- What are the barriers that constrain the integration of Lean and JIT in sustainable spare parts management, and how can these barriers be addressed?

These questions discussed both the supporting mechanisms and the challenges of using Lean and JIT approaches in spare parts management with a focus on sustainability. These insights also offered practical guidance for managers and policymakers seeking to enhance supply chains in alignment with global sustainability objectives.

The research model has three components:

- **Independent Variables:** Lean and JIT practices (5S, value stream mapping, Kaizen systems, Total Productive Maintenance).
- **Dependent Variables:** Sustainability performance outcomes synchronized with SDG 12—waste reduction, improved resource efficiency, and enhanced inventory management.
- **Moderating Factors:** Operational resilience (capacity to maintain performance in a situation of variability in demand and supply disruptions). Resilience is also added as a moderating factor, and it is understood that sustainable Lean/JIT performance needs to be able to absorb disruptions and still continue operations.

Figure 1. Structural Equation Model of the Research Framework

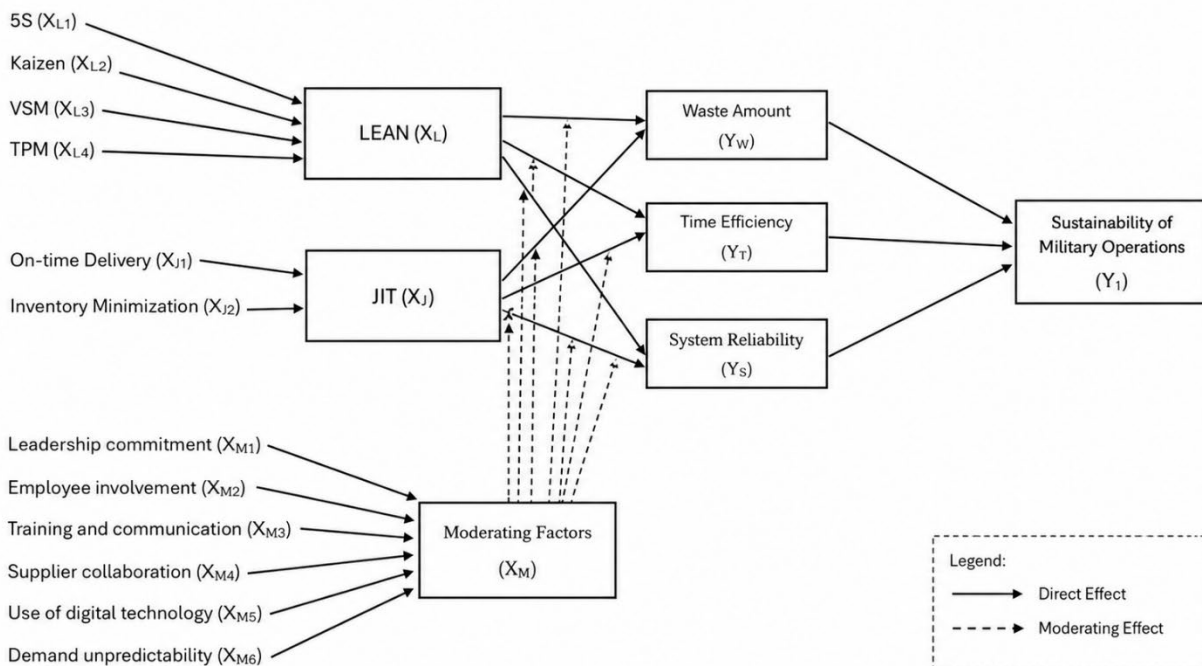


Figure 1. Conceptual Research Model

3. Methods

This research study employed a quantitative methodology to investigate the role of Lean and Just-In-Time (JIT) spare parts management practices in advancing the Sustainable Development Goals (SDGs). The greatest attention was paid to SDG 12 Responsible Consumption and Production. The research study aimed at taking the factors of organizational process, perceptions of the individuals, and the situation. The quantitative method is an appropriate approach to present descriptive information that cannot be obtained with quantitative data alone (Chris, 2021).

3.1 Philosophy and Approach to the Research

The study is based on the interpretive philosophical perspective, the focus of which is the perception and interpretation of the phenomena by individuals within their individual contexts (Pervin and Mokhtar, 2022). This methodology is the most appropriate in investigating how the operational managers and supply chain experts experience, apply, and analyze Lean and JIT practices within the context of the sustainable spare parts logistics niche. Unlike the positivist approaches that set out to test characterizing individuals by statistical figures, interpretive approaches seek to explore human behavior by directly addressing the experiences of participants. Therefore, the research study used an inductive

logic of inquiry, which allows themes, categories, and meanings to be revealed through the data and not be defined in a priori constructs (Naeem et al., 2023).

3.2 Research Design

The study was based on a cross-sectional, exploratory study where cross-industry professionals involved in spare parts management and sustainability practices have been approached to provide quantitative data. Although there is no intention to statistically generalize the results of the research, as it is currently set, a more analytic approach to the topic was carried out by gathering textual data. To achieve this, a quantitative research was undertaken, involving a semi-structured questionnaire with closed-ended questions. Whilst interviews and focus groups tend to be used regularly in quantitative research, the quantitative survey paves the way to gather the extensive views of sample participants in a variety of sectors, geographical locations, and scales, and does so without the need to do so in a live communication format. The method is most appropriate to provide descriptive information on organizational practices, perceptions, and issues that are associated with implementing Lean and JIT in the management of spare parts.

This study commenced its analysis scope at the stage of creating a spare-parts order in the organization and ends at the delivery to the maintenance units by the suppliers, as well as its warehousing and consumption. Upstream supply processes were not considered in the study. The scope that defines the extent of scope between the order stage and the shipment and internal usage stage have put this research narrowly to the operational aspects of Lean and JIT that have a direct impact on inventory efficiencies, reliability, and sustainability practice.

4. Data Collection

The core data collection tool is a semi-structured questionnaire with exclusive closed-ended questions. The design of the questionnaire synchronizes with the study's research model and objectives. Each section of the survey was designed to collect responses while maintaining flexibility for participants to show their experiences and perspectives. The questionnaire was divided into five thematic sections:

- Organizational Background – collects data from the Military sector.
- Lean and JIT Practices – collects insights on special tools used (e.g., Kaizen, 5S, value stream mapping, and Total Productive Maintenance) and how they are applied in spare parts logistics.
- Sustainability Outcomes – studies the mindsets of participants and examines how these practices result in waste minimization, inventory efficiency, energy savings, and alignment with SDG 12.
- Success Factors – studies in detail the enablers, such as leadership support, supplier collaboration, employee training, and digital tools, that facilitate the implementation of Lean and JIT.
- Barriers and Limitations – find out the organizational, operational, and external barriers that impede the effective adoption of Lean and JIT in the context of sustainable spare parts management.

On September 3, 2025, I sent out a questionnaire to find out how Lean and Just-In-Time (JIT) methods in spare parts management can help us reach sustainability, with a focus on Sustainable Development Goal 12 (Responsible Consumption and Production) as shown in Table 1. The survey was sent to people who were directly involved with or concerned about managing spare parts in order to get their thoughts and real-life experiences. We got 30 responses, which gave us useful information to look at how Lean and JIT methods can help this important area of operations become more efficient, cut down on waste, and encourage sustainable consumption and production. Using the Minitab statistical application, the data from the questionnaire were carefully analyzed. This gave a clear and organized picture of the results. Minitab's advanced regression, correlation, and graphical tools made it easy to find patterns and connections between Lean and Just-In-Time (JIT) practices and their effects on sustainability. The analysis showed that these practices help reduce waste, make better use of resources, and support Sustainable Development Goal 12 (Responsible Consumption and Production). Not only did Minitab turn the data into useful insights, but it also showed them in a way that was easy to understand with charts, residual plots, and model summaries. This made the findings more trustworthy, clear, and useful for making decisions (Table 1).

Table 1. Details of Questionnaire

Item	Details
Date of Questionnaire	3rd September 2025

Purpose	To explore how Lean and Just-In-Time (JIT) practices in spare parts management contribute to sustainability, focusing on SDG 12 (Responsible Consumption and Production)
Target Group	Individuals concerned with spare parts management
Method	Questionnaire / Survey
Number of Responses	30
Key Focus	Examining how Lean and JIT enhance efficiency, reduce waste, and support sustainable consumption and production

5. Results and Discussion

5.1 Regression Analysis: Linking Lean/JIT Practices to SDG12 (Sustainability Outcomes)

This section presented a focused regression analysis to investigate how Lean and Just-In-Time (JIT) spare-parts management practices relate to perceived sustainability outcomes, operational efficiencies, and the enabling role of technology and supplier collaboration. The analysis was used to survey responses (n = 30) collected via a structured questionnaire covering.

5.2 Multiple Regression

The predictors consist of Lean and JIT practices, captured through a set of quantifiable survey measures denoted as $X_1, X_2, \dots$

$$Y_1 = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \dots + \beta_n X_n + \varepsilon$$

Where:

Y_1 = Sustainability Benefits (Q16)

α = Constant (baseline sustainability when all predictors are zero)

β = Coefficients (weights showing the contribution of each variable)

ε = Error term

▪ Variable Mapping (from questionnaire):

- **Lean-related variables (X_{L1} – X_{L4}):**

X_{L1} = Application of 5S (Q1)

X_{L2} = Application of Kaizen (Q2)

X_{L3} = Value Stream Mapping (VSM) (Q3)

X_{L4} = Total Productive Maintenance (TPM) (Q4)

- **JIT-related variables (X_{J1} – X_{J2}):**

X_{J1} = On-time Delivery (Q5)

X_{J2} = Inventory Minimization (Q6)

- **Moderated-related variables (X_{M1} – X_{M6}):**

X_{M1} = Leadership Commitment (Q7)

X_{M2} = Employee Involvement (Q8)

X_{M3} = Training and Communication (Q9)

X_{M4} = Supplier Collaboration (Q10)

X_{M5} = Use of Digital Technology (Q11)

X_{M6} = Demand unpredictability (Q12)

▪ Final Equation Form:

Sustainability (Y)

$$= \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{11} X_{11} + \beta_{12} X_{12} + \varepsilon$$

▪ Explanation:

- **Lean block (X_{L1} – X_{L4}):** Captures organizational culture, training, leadership, and use of Lean tools. Strong β -values here indicate that sustainability depends on process discipline and waste elimination.

- **JIT block (X_{J1} – X_{J2}):** Captures responsiveness, on-time delivery, and inventory efficiency. Positive β -values

here show that sustainability improves with better synchronization and reduced waste.

- **Moderate Factors block (X_{M1}- X_{M6}):** This block captures training, leadership, the use of digital technology, and employee involvement. Strong β -values here indicate that sustainability depends on the process effectively; these elements are applied and integrated. Strong β -values for this block indicate that sustainability outcomes rely heavily on process efficiency, organizational support, and capability development.

Together, the model quantitatively links Lean and JIT practices to sustainability outcomes (SDG 12).

5.2.1 First Regression: Y₁ refers to the Outcome of the Sustainability of Military Operations

In this regression output, the coefficients table shows how much each independent variable helps explain the dependent variable, as well as checks for significance and multicollinearity. The coefficient for the constant term is 0.978, but its p-value (0.212) shows that it is not statistically significant. Most of the predictors, like XL1, XL2, XL3, XJ1, XJ2, XM2, XM3, XM4, XM5, and XM6, have p-values that are relatively high (all greater than 0.05), which means they do not add much to the model. XL4, which has a coefficient of 0.388 and a p-value of 0.026, and XM1, which has a coefficient of 0.356 and a p-value of 0.045, are two predictors that stand out as statistically significant. Both of these variables have positive coefficients, which means that when XL4 and XM1 go up, the dependent variable also goes up. The t-values for these two variables also show that they are important.

5.3 Numerical Results

In the regression output shown in Figure 2The coefficients table shows how much each independent variable helps explain the dependent variable, as well as checks for significance and multicollinearity. The coefficient for the constant term is 0.978, but its p-value (0.212) shows that it is not statistically significant. Most of the predictors, like XL1, XL2, XL3, XJ1, XJ2, XM2, XM3, XM4, XM5, and XM6, have p-values that are relatively high (all greater than 0.05), which means they don't add much to the model. XL4, which is Total Productive Maintenance, has a coefficient of 0.388 and a p-value of 0.026, and XM1, which is Leadership Commitment, has a coefficient of 0.356 and a p-value of 0.045, are two predictors that stand out as statistically significant. Both of these variables have positive coefficients, which means that when XL4 and XM1 go up, the dependent variable also goes up. The t-values for these two variables also show that they are important (See Figure 3, Figure 4, Figure 5).

Model Summary

S	R-sq	R-sq(adj)
0.713153	70.56%	49.78%

Regression Equation

$$Y_1 = 0.978 - 0.043 XL1 - 0.140 XL2 - 0.070 XL3 + 0.388 XL4 - 0.131 XJ1 + 0.154 XJ2 \\ + 0.356 XM1 + 0.025 XM2 + 0.043 XM3 + 0.328 XM4 + 0.046 XM5 - 0.145 XM6$$

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0.978	0.755	1.30	0.212	
XL1	-0.043	0.217	-0.20	0.846	2.69
XL2	-0.140	0.193	-0.73	0.478	2.43
XL3	-0.070	0.203	-0.34	0.735	2.39
XL4	0.388	0.159	2.44	0.026	2.10
XJ1	-0.131	0.161	-0.81	0.429	2.69
XJ2	0.154	0.169	0.91	0.376	2.48
XM1	0.356	0.164	2.17	0.045	2.49
XM2	0.025	0.120	0.21	0.835	1.61
XM3	0.043	0.225	0.19	0.852	4.30
XM4	0.328	0.255	1.29	0.214	4.94
XM5	0.046	0.244	0.19	0.852	4.16
XM6	-0.145	0.204	-0.71	0.485	4.41

Figure 2. First Regression Y (Regression Equation, Model Summary, and Coefficients)

5.4 Graphical Results

Figure 3 shows that the residuals generally follow a straight-line pattern, indicating that the normality assumption of the regression model is reasonably satisfied.

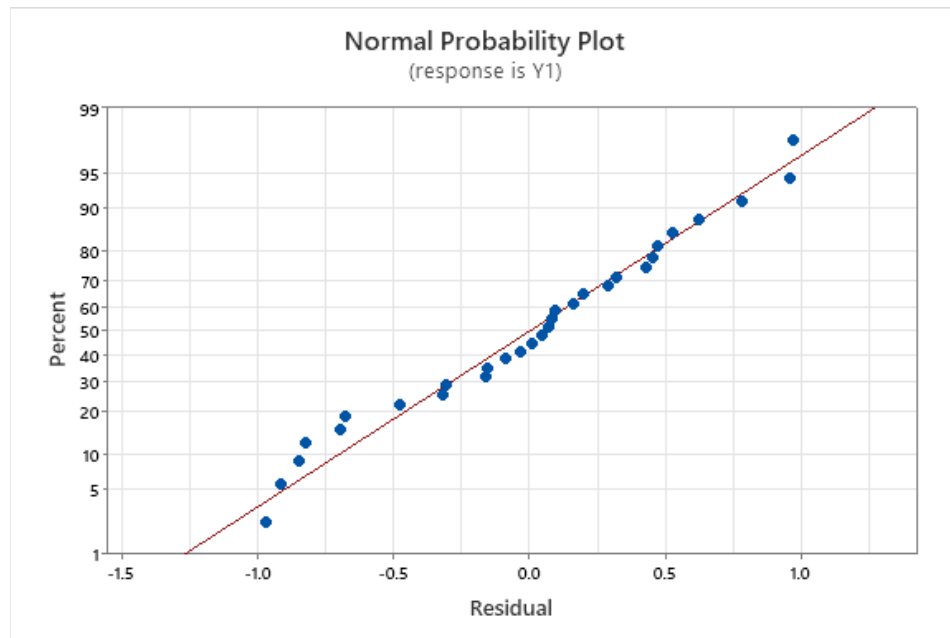


Figure 3. First Regression Y₁ (Normal Probability Plot Y₁)

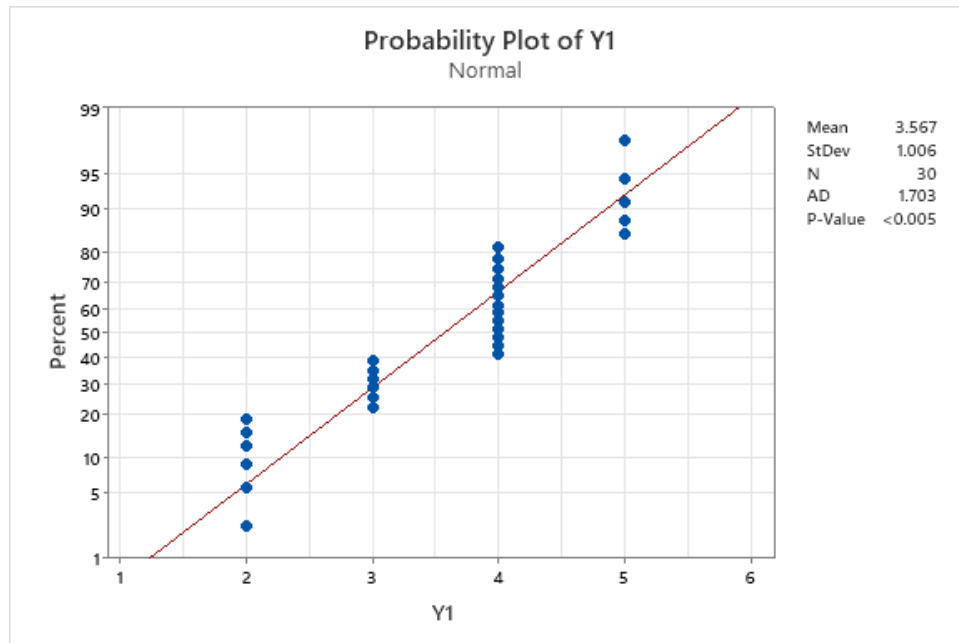


Figure 4. First Regression Y₁ (Probability Plot of Y₁)

Figure 4 further confirms that the residuals are approximately normally distributed, as most points lie close to the reference line with only minor deviations.

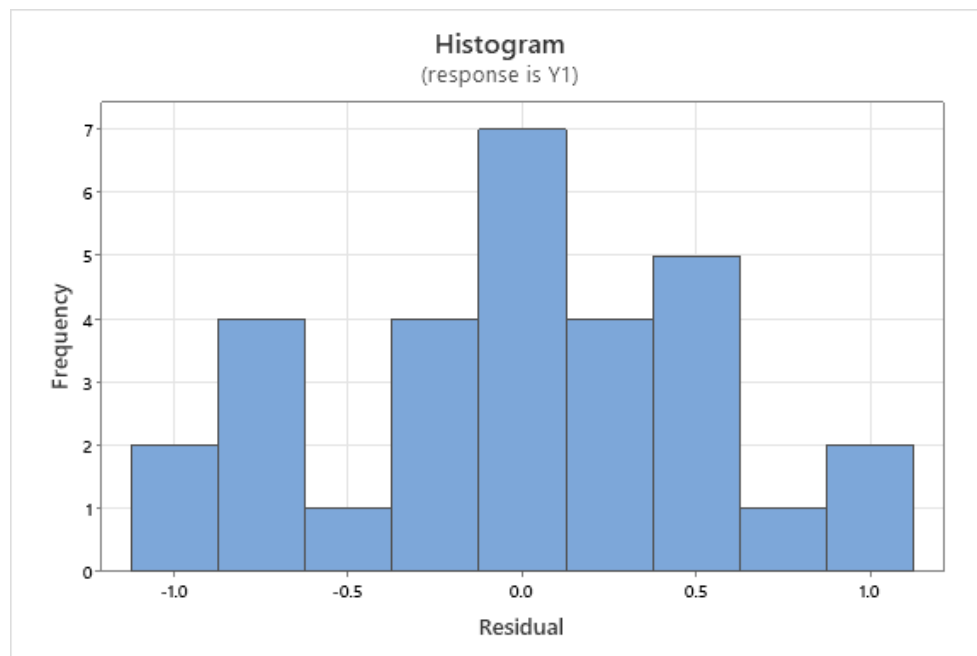


Figure 5. First Regression Y₁ (Frequency Vs Residual Histogram)

Figure 5 presents the distribution of residuals. The histogram is approximately bell-shaped and centered around zero, suggesting that the regression model errors are normally distributed and that no major violations of regression assumptions are present.

5.5 Proposed Improvements

The study will be improved by increasing the sample size to enhance the reliability and generalizability of the results. A larger sample will allow for better statistical analysis and more accurate representation of the target population. In addition, semi-structured interviews will be conducted with selected participants to gather deeper qualitative insights and complement the survey findings. These interviews will help capture detailed perspectives that may not be fully reflected in quantitative responses.

Furthermore, additional numerical analysis will be included, such as expanded descriptive statistics, correlation analysis, and comparative evaluation of key variables. These analyses are expected to provide clearer evidence of relationships among lean practices, circular economy principles, and sustainability outcomes. Graphical results will also be enhanced by adding bar charts, pie charts, and trend graphs to visually illustrate improvements and comparisons, making the findings easier to interpret.

Moreover, advanced digital analytics tools will be integrated to improve forecasting accuracy and model precision. Techniques such as predictive analytics and data visualization dashboards will support better decision-making and provide more robust validation of the proposed framework. These improvements are expected to strengthen the overall quality of the study and provide more comprehensive and actionable results.

5.6 Validation

To strengthen the validation of the proposed framework, additional statistical hypothesis tests will be conducted. The study will apply reliability analysis using Cronbach's alpha to confirm the internal consistency of the survey constructs. Construct validity will also be assessed through factor analysis to ensure that the measurement items properly represent the intended variables.

Furthermore, inferential statistical tests such as t-tests and ANOVA will be used to examine differences between groups where applicable. Correlation analysis and multiple regression analysis will be performed to test the relationships between lean practices, circular economy adoption, and sustainability performance. These tests will help determine whether the observed relationships are statistically significant.

Hypothesis testing will be conducted at a 95% confidence level ($p < 0.05$) to validate the research assumptions. The results will confirm whether the proposed improvements have a significant impact on operational efficiency and environmental performance. In addition, model validation will be enhanced by comparing predicted values with actual outcomes to evaluate forecasting accuracy. These validation steps are expected to increase the credibility and robustness of the study findings.

6. Conclusion

The research study has addressed the question of how Lean and Just-In-Time (JIT) spare parts management processes may be combined as a strategic means of attaining Sustainable Development Goal 12 (SDG 12): Responsible Consumption and Production. It also used three fundamental research questions, namely: how Lean and JIT lead to sustainability, the success factors that make their implementation effective, and the reasons that prevent their implementation. The results of the study provided an in-depth research of the convergence of operations efficiency and environmental responsibility in the area that has rarely been discussed previously, spare parts logistics.

The research validated that Lean and JIT could be utilized in the reduction of cost and enhancement of operational performance, but also as a very effective way of enabling sustainability. By reducing wastage, limiting overstocking, and managing more efficiently available sources, these activities also contribute directly to the goals of SDG 12. Within a variety of military operations in spare part management, the respondents mentioned tangible improvements they obtained by utilizing Lean and JIT in their spare parts operations. These were smaller lead times, less downtime, better maintenance efficiency, and well-fitting sustainability policies. JIT approaches combined with such Lean tools as Kaizen, value stream mapping (VSM), 5S, and total productive maintenance (TPM) made the whole supply chain more agile and environmentally friendly.

The study also indicated that the implementation process should largely rely on several essential enablers. Commitments to leadership, employee participation, the work of suppliers, and the use of digital technologies became critical factors of success. An organization that had a culture of continuous improvement and strategic leadership had a higher ability to overcome the complexities that are attached with Lean and JIT integration. The digital tools were

crucial towards enhancing the visibility of inventory, accuracy in forecasting, and responsiveness, thus maximizing the sustainability impact of such operational practices.

A few obstacles remain that hamper the extensive implementation of Lean and JIT in spare parts logistics despite the mentioned strengths. Leading these are fluctuations in demand, organizational change rejection, shortage of digital infrastructure, and the cost of training and system upgrade, which is very expensive. Lean inventories may be operationally risky in those industries whose spare parts usage is erratic and in which downtime is expensive. These obstacles support the importance of hybrid solutions, including the incorporation of Lean proficiency with the incorporation of strategic inventory cushions in the effort to enhance resilience and flexibility. Furthermore, the results indicated that Lean and JIT systems require adaptation to the peculiarities of spare parts logistics instead of applying to the traditional production models only.

In conclusion, this research demonstrated that Lean and JIT spare parts management practices can serve as effective vehicles for achieving SDG 12, provided that organizations address the associated challenges through targeted enablers and strategic adaptation. The insights gained offer valuable guidance for operations managers, sustainability officers, and policymakers aiming to design supply chains that are not only efficient but also environmentally responsible.

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Biographies

Dr. Pilsung Choe is a faculty member in the Department of Mechanical and Industrial Engineering at Qatar University. He holds a Ph.D. in Industrial Engineering from Purdue University, West Lafayette in the United States. His research focuses on human factors and behavior, HCI and UX, user circular behavior, e-society, security, data analysis, and engineering management. Dr. Choe has published on these topics in a variety of academic journals and conference proceedings.

Hamad ALMasqari is a Mechanical Engineer who has worked in three different companies, such as Orbital Projects and Service Engineering Company (OPSE), then I have moved to an operating engineer position in BotharBoring and tunneling operation construction company, and until now I am working as a mechanical engineer in Qatar Energy, where I have experienced working and operating different processes. Other than a professional job, I have done my internship in Oman Gas Company (OGC) in the maintenance department. Through my career journey, I have learned and experienced various situations. At some points, I felt like I needed to develop my educational profession through completing my learning process. Now I have completed my Master's in Engineering Management to complete my career goal.

Appendix:

Questionnaire

Welcome Note

Dear Participant,

This survey is part of an academic investigation to explore how Lean and Just-In-Time (JIT) practices in spare parts management contribute to achieving sustainability, particularly SDG 12 (Responsible Consumption and Production). Your answers will remain confidential and anonymous, and the results will be used for academic purposes only. Please answer all questions to the best of your knowledge and professional experience. The survey will take approximately 10 minutes to complete.

We sincerely thank you for your valuable time and cooperation.

Instructions

Based on your experience and expertise in your department, please rate the current status of the following factors in the context of spare parts management:

Scale:

- 1 = Very Bad (0-20%)
- 2 = Bad (20-40%)
- 3 = Moderate (40-60%)
- 4 = Good (60-80%)
- 5 = Excellent (80-100%)

1. Application of Lean tool (5S)

☐ Very Bad (0-20%) ☐ Bad (20-40%) ☐ Moderate (40-60%) ☐ Good (60-80%) ☐ Excellent (80-100%)

2. Application of Lean tool (Kaizen).

☐ Very Bad (0-20%) ☐ Bad (20-40%) ☐ Moderate (40-60%) ☐ Good (60-80%) ☐ Excellent (80-100%)

3. Application of Lean tool (VSM).

VSM refers to value stream mapping

☐ Very Bad (0-20%) ☐ Bad (20-40%) ☐ Moderate (40-60%) ☐ Good (60-80%) ☐ Excellent (80-100%)

4. Application of Lean tool (TPM).

TPM refers to Total Productive Maintenance

☐ Very Bad (0-20%) ☐ Bad (20-40%) ☐ Moderate (40-60%) ☐ Good (60-80%) ☐ Excellent (80-100%)

5. On-time Delivery rate for materials and spare parts.

☐ Very Bad (0-20%) ☐ Bad (20-40%) ☐ Moderate (40-60%) ☐ Good (60-80%) ☐ Very good (80-100%)

6. Inventory minimization in spare parts management.

☐ Very Bad (0-20%) ☐ Bad (20-40%) ☐ Moderate (40-60%) ☐ Good (60-80%) ☐ Excellent (80-100%)

7. Leadership commitment to Lean/JIT initiatives.

☐ Very Bad (0-20%) ☐ Bad (20-40%) ☐ Moderate (40-60%) ☐ Good (60-80%) ☐ Excellent (80-100%)

8. Employee involvement in Lean/JIT practices.

☐ Very Bad (0-20%) ☐ Bad (20-40%) ☐ Moderate (40-60%) ☐ Good (60-80%) ☐ Excellent (80-100%)

9. Training and communication effectiveness

☐ Very Bad (0-20%) ☐ Bad (20-40%) ☐ Moderate (40-60%) ☐ Good (60-80%) ☐ Excellent (80-100%)

10. Supplier collaboration in spare parts management.

☐ Very Bad (0-20%) ☐ Bad (20-40%) ☐ Moderate (40-60%) ☐ Good (60-80%) ☐ Excellent (80-100%)

11. Use of Digital technology (ERP, AI and EDI) for tracking spare parts.

ERP refers to Enterprise Resource Planning

AI refers to Artificial Intelligence

EDI refers to electronic data exchange

☐ Very Bad (0-20%) ☐ Bad (20-40%) ☐ Moderate (40-60%) ☐ Good (60-80%) ☐ Excellent (80-100%)

12. Demand unpredictability in spare parts management.

☐ Very Bad (0-20%) ☐ Bad (20-40%) ☐ Moderate (40-60%) ☐ Good (60-80%) ☐ Excellent (80-100%)

13. Effectiveness of waste reduction efforts.

☐ Very Bad (0-20%) ☐ Bad (20-40%) ☐ Moderate (40-60%) ☐ Good (60-80%) ☐ Excellent (80-100%)

14. Human efficiency (based on working hours).

☐ Very Bad (0hrs 0-20%) ☐ Bad (2hrs 20-40%) ☐ Moderate (4hrs 40-60%)

☐ good (6hrs) (60-80%) ☐ Excellent (8hrs 80-100%)

15. Machine efficiency (based on meantime between failure)

☐ Very Bad (100hrs) ☐ Bad (200hrs 20-40%) ☐ Moderate (300hrs 40-60%)

☐ Good (400hrs 60-80%) ☐ Excellent (500hrs 80-100%)

16. Sustainability benefits gained from Lean/JIT practices.

☐ Very Bad (0-20%) ☐ Bad (20-40%) ☐ Moderate (40-60%) ☐ Good (60-80%)

☐ Excellent (80-100%)