Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/NA11.20260157
Published: June 9, 2026

Integrating Lean and Industry 4.0 in Transportation Logistics: A Case Study of Cost Reduction and Digital Transformation

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Abstract

This article explores a structured cost-reduction and process improvement initiative in the Transportation Logistics function of the OEM manufacturing industry - an area often viewed as transaction, and non-value-adding. The initiative aimed to achieve a 10% annual cost reduction through a global Continuous Improvement program that combined data-driven analysis, cross-functional collaboration, and adapted Lean Six Sigma methodologies. A strategic prioritization exercise identified high-impact initiatives, highlighting the P44 project as a major transformation effort. Initiatives were implemented within a scalable framework comprising Quick Projects, Major Projects, and Kaizen Events, complemented by change management practices such as readiness surveys to foster lean thinking and technology adoption across regions. Beyond the use of traditional tools like process mapping, Fishbone, and Affinity diagrams, the program leveraged advanced technologies, particularly the AI-enabled capabilities of P44, to enhance visibility and decision-making in global logistics operations. Importantly, this case study moves beyond conventional lean narratives by demonstrating a practical framework for integrating Lean principles with Industry 4.0 (I4.0) technologies, reimagining transportation logistics as a strategic driver of organization-wide efficiency and value creation. This paper contributes empirical evidence demonstrating how Lean governance, process standardization, and Industry 4.0 technologies can be operationally integrated within transactional transportation logistics. The study further proposes a Transportation Lean-I4.0 implementation framework that links Lean process discipline with digital capability development and organizational change management.

Keywords
Lean strategies, Artificial Intelligence, Global Logistics, Change Management, Transformation program management

1. Introduction
Global transportation logistics operate under persistent pressure to reduce costs while maintaining service reliability, particularly in original equipment manufacturer (OEM) environments. Logistics is often perceived as non-value-adding overhead rather than a strategic contributor (Argiyantari et al., 2022). These pressures intensified post-COVID-19 and exposed structural vulnerabilities in global transportation systems, supplier dependencies, and information

flows along with geopolitical instability (Shibasaki et al., 2021). In response, organizations have increasingly pursued digital transformation initiatives to enhance visibility, coordination, and decision-making in transportation logistics (El Jaouhari et al., 2023).

Firms are adopting Industry 4.0 technologies such as big data analytics, the Internet of Things (IoT), automation, and cyber-physical systems to enable real-time monitoring and data-driven decision-making (Rossini et al., 2023). However, prior research highlights that technology adoption alone does not guarantee performance improvement. Logistics 4.0 initiatives often underperform due to poorly defined processes, fragmented workflows, and existence of non-value-adding activities (Barreto et al., 2017).

Lean thinking emerged as a critical enabler of effective Industry 4.0 implementation. By emphasizing waste elimination, process standardization, and continuous improvement, lean practices provide the operational discipline required for successful digitalization (Tortorella et al., 2017). Empirical studies indicate that lean supply chains facilitate Industry 4.0 adoption by stabilizing processes and supporting horizontal and vertical integration (Núñez-Merino et al., 2020; McDermott et al., 2024), while also enhancing transportation performance in complex and regulated environments (Argiyantari et al., 2022).

Together, lean principles and Industry 4.0 technologies form a complementary pathway toward Logistics 4.0 (Rossini et al., 2023). Despite growing conceptual research, detailed case-based evidence of their joint application in transportation logistics remains limited (Dossou et al., 2022; Gomes et al., 2025). Addressing this gap, this study presents an in-depth case study of a global transportation logistics operation responding to a corporate mandate for year-over-year cost reductions, offering practical insights into building lean and digitally enabled logistics capabilities. Existing studies primarily examine Lean and Industry 4.0 either as separate improvement paradigms or as broad conceptual complements. Limited research explains how Lean governance structures, process standardization practices, and digital technologies interact operationally within transactional transportation logistics environments. Furthermore, empirical evidence remains scarce regarding how organizations translate Industry 4.0 investments into measurable logistics process improvements through Lean-Industry 4.0 based implementation.

1.1 Objectives

This study aims to examine how Lean principles and Industry 4.0 (I4.0) technologies can be systematically integrated to improve cost efficiency and operational performance within transportation logistics functions in OEM manufacturing environments. Specifically, the research pursues three objectives: (1) to develop and document a structured continuous improvement framework that enables scalable cost-reduction initiatives in transactional logistics operations; (2) to analyze how data-driven prioritization and cross-functional collaboration support the effective deployment of digital logistics platforms, particularly AI-enabled visibility solutions; and (3) to evaluate the organizational enablers and change management practices required to sustain Lean–I4.0 integration across global operations. By addressing these objectives, the study seeks to provide empirical evidence bridging conceptual Logistics 4.0 research and practical implementation.

2. Literature review

Global transportation logistics has become increasingly complex as supply chains expand across regions characterized by regulatory heterogeneity, geopolitical risk, and infrastructure constraints. Although global logistics research spans areas such as international trade, intermodal transport, sustainability, and digitalization, the literature remains fragmented, limiting an integrated understanding of logistics connectivity and resilience in a global context (Shibasaki et al., 2021). This fragmentation is also evident in international supply chain decision-making studies, which are dispersed across sourcing, location, and policy dimensions, constraining comparative insight into how firms manage logistics risk at scale.

Lean Supply Chain Management (LSCM) has been widely recognized as a mechanism for improving logistics efficiency through waste reduction, flow optimization, and process integration (Argiyantari et al., 2022). However, early studies often treated LSCM at a conceptual level, without clearly delineating concrete practice bundles. Tortorella et al. (2017) empirically validating LSCM bundles such as internal process integration, supplier collaboration, and demand-flow synchronization and demonstrating their performance implications in supply chain.

In transportation settings, lean thinking found relevance in regulated industries, where Argiyantari et al. (2022) provide empirical evidence that lean waste elimination practices can significantly enhance transportation performance.

The emergence of Industry 4.0 further reshaped transportation logistics through the adoption of technologies such as IoT, big data analytics, automation, and cyber-physical systems (Rossini et al., 2023). Systematic reviews indicate that these technologies enhance real-time visibility, process integration, and operational performance across logistics and supply chain functions (El Jaouhari et al., 2023; Thiyagarajan et al., 2022). However, Logistics 4.0 research often lacks a structured articulation of the capability bundles required for effective implementation (Barreto et al., 2017). Lean and Logistics 4.0 literature emphasizes that Industry 4.0 technologies such as IoT, big data analytics, artificial intelligence, and digital integration enhance supply chain visibility, responsiveness, and resilience. Research shows that digital technologies improve supply chain risk analytics by enabling real-time monitoring, predictive analysis, and mitigation of disruption ripple effects across supply networks (Ivanov et al., 2019). Industry 4.0 capabilities also strengthen digital supply chain integration and decision-making efficiency (Queiroz et al., 2021). Furthermore, Lean principles are reinforced through automation, smart manufacturing, and data-driven continuous improvement, which reduce waste and optimize operational performance (Sanders et al., 2016). Recent studies highlight that combining Lean practices with Industry 4.0 improves resilience and disruption management by increasing agility, adaptability, and information sharing across supply chains (Ismail et al., 2025). These approaches collectively support proactive risk management and long-term supply chain resilience (Wieland & Durach, 2021).

Recent literature emphasizes the synergistic relationship between lean and Industry 4.0, arguing that lean supply chains provide a necessary foundation for effective digitalization, while digital technologies amplify lean outcomes (Núñez-Merino et al., 2020; McDermott et al., 2024). AI and Industry 4.0 make process improvement initiatives more adaptive, precise, data driven and impactful, enabling faster insights, smarter decision making and more sustainable long-term performance gains (Gopalakrishnan and Augustine, 2026; Thiyagarajan et al., 2022). Empirical evidence from transportation logistics further supports this view, demonstrating how lean tools facilitate digital transformation and organizational learning in complex logistics environments (Gomes et al., 2025).

Collectively, prior literature suggests that Lean and Industry 4.0 should not be viewed as independent operational initiatives, but as interdependent capability systems. Lean establishes process discipline, waste visibility, and standardized workflows, while Industry 4.0 technologies enhance real-time analytics, automation, and adaptive decision-making (Sanders et al., 2016; Ivanov et al., 2019). However, existing research remains largely conceptual and provides limited guidance regarding how these complementary capabilities can be operationalized within transportation logistics environments characterized by transactional complexity, geographically dispersed operations, and cross-functional coordination requirements.

Despite growing interest in Lean–Industry 4.0 integration, three major gaps remain. First, most studies emphasize manufacturing environments, with limited empirical attention to transactional transportation logistics operations. Second, prior research often discusses Lean and digitalization conceptually without demonstrating the operational mechanisms linking process standardization, leadership, analytics, and digital tools. Third, limited case-based evidence exists showing how organizations can scale Lean-I4.0 initiatives across geographically dispersed logistics networks. This study addresses these gaps through an in-depth case analysis of a global OEM transportation logistics transformation initiative.

3. Methods

This study adopts a case study reporting approach to document the adoption of Lean principles and Industry 4.0 technologies within a global supply chain and transportation logistics context (Gomes et al., 2025). In addition to conducting a qualitative inquiry, the study systematically reports the transformation process, implementation steps, and practical outcomes of a real-world supply chain modernization initiative (Dossou et al., 2022). This approach is appropriate given the limited availability of detailed case reports describing operational Lean-Industry 4.0 integration in Transportation logistics or “Transportation Lean-I4.0 framework”. The research framework followed in this study is shown in Figure 1.

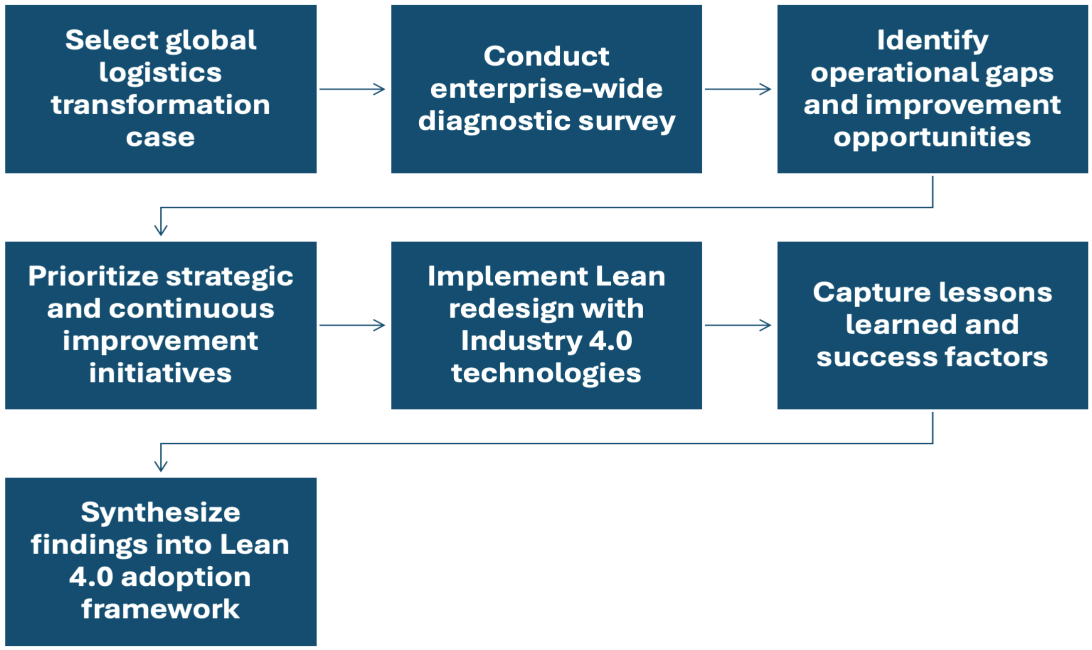

Figure 1. Transportation Lean-I4.0 methodology

The case involves a global logistics operation undergoing a structured Lean transformation alongside the deployment of digital visibility technologies. The Transportation Lean-I4.0 framework was documented across four phases. First, an enterprise-wide diagnostic survey identified operational gaps and improvement opportunities, forming the basis for a data-driven business case. A comprehensive maturity assessment survey was developed by the project steering committee to evaluate the organization's Process Axis. The instrument comprised 177 questions across four business areas: Inbound, Outbound, Global CFS (Consolidated Freight Solution), and Compound logistics. Additional details are provided in the Appendices 1. Questions were grouped into thematic clusters and deployed to 20 SMEs across five global regions to establish a representative operational baseline. Second, initiatives were prioritized into strategic and continuous improvement projects, including Lean process redesign supported by digital platform adoption (Project 44) and future-state capability assessment. Third, projects were implemented using structured improvement practices and monitored through operational performance metrics. Finally, lessons learned and success factors were synthesized into a Transportation Lean-I4.0 adoption framework, offering a practical and replicable roadmap for similar transformations.

3.1 Case Selection Rationale

A single embedded case study design was selected because the research aims to investigate a contemporary organizational transformation phenomenon within its real-world operational context (Gomes et al., 2025). The selected organization represented an information-rich case due to its global logistics scale, structured Lean transformation program, and simultaneous deployment of Industry 4.0 technologies across multiple transportation functions. This design enabled detailed examination of process interactions, organizational practices, and implementation mechanisms that are difficult to capture through survey-based approaches alone.

4. Data Collection and Analysis

Following the collection of survey responses, the results were reviewed and validated by senior business leaders to ensure accuracy and relevance. In collaboration with the Steering Committee, nine critical focus areas were identified across multiple business functions. These focus areas represented systemic gaps affecting operational efficiency, visibility, and decision-making. Each focus area was addressed through defined countermeasures (Table 1), selected based on complexity, scope, and functional ownership. The last column of the table summarizes the I4.0 capabilities that were created as a result of the implemented countermeasures as well as the impact to the business.

Table 1. Summary of Industry 4.0 countermeasures and capabilities

Business area	**Problem addressed/Focus Area**	**Countermeasure Implemented**	**Benefits/Transportation Lean-I4.0 Capabilities created**
Inbound / Outbound Logistics	- Lack of process to measure exception in Air shipments - Lack of process to measure weekly Ocean carrier capacity vs confirmed booking - identify early shortage - Lack of process to measure backlog of payment for Ocean - Lack of process to measure Demurrage of Ocean containers	- Global Process Alignment sessions: Air exceptions, Ocean Carrier capacity planning processes & Ocean payment and Container Demurrage exception - P44 for Air & Demurrage - Global Booking Tool - Expanded Usage of Orca (Accounts payable tool)	- Process standardization (tracking file among various providers) - AI & Digital Twins - Increased visibility and decision making - Improve Supply chain analytics capability - >90% reduction in Demurrage cost - Achieved an 82% improvement in invoice payment efficiency
Global CFS (Consolidated Freight Solution)	- Lack of process for comparing schedules to measure drop-in/out for plants - Inability to manage returnable racks and re-order points for service providers	- Global Governance Alignment session for all CFS Poles - Expanded use of Risk-avoidance and Datalake tools	- Process standardization - Big Data Analytics - Increased decision making due to better reporting - Substantial reduction of CFS risks
Compound Operations	- Lack of a storage process in the yard : Product Geolocation - Lack of Global Quality and Aging management system - Lack of process to weigh and measure export units	- Reviews on Quality and Safety with global alignment on reporting/process - Global Yard Management System - Standardized DQR Rollout (with Quality and logistics teams)	- Process standardization - Digital Twin - Instantaneous identification of units in the yard - Robust Quality audit process implemented - Several tactical actions taken to address quality & Aging/deterioration of units - 100% Elimination of Very High Safety risks due to handling and transport of units

The Kaizen events applied a systematic approach from problem identification to solution development. Beginning with "Learning to see" activity where participants visualize transactional logistics processes: end-to-end workflows, system interfaces, and decision points. During process mapping, teams identified operational pain points and sources of waste. These issues were consolidated using an Affinity Diagram to group related observations and establish common themes for further analysis. Root cause analysis was conducted using Fishbone (Ishikawa) diagrams or 5-Why analysis. Proposed improvement actions were then evaluated using an Impact vs. Effort Prioritization Matrix. Initiatives were classified as Quick Wins (high impact, low effort) for immediate execution (Wave 1), Strategic Projects (high impact, high effort) for longer-term planning (Wave 2), Fill-ins (low impact, low effort), or Value-Negative initiatives (low impact, high effort), which were excluded. This structured approach ensured that the final project pipeline was both value-driven and feasible, aligning improvement initiatives with organizational strategy, execution capacity, and resource availability, while demonstrating the adaptability of Kaizen to transactional logistics environments.

5. Results and Discussion

This case study demonstrates the operational synergy between Lean Management and Industry 4.0 within transportation logistics. While the theoretical intersection of these frameworks is well-documented, practitioners in 2026 often face "pilot purgatory"-implementing digital tools without empirical roadmaps for waste reduction or human-centric development. This research provides a tangible blueprint for organizations struggling to bridge the gap between high-tech I4.0 adoption and fundamental Lean principles.

This paper proposes a process improvement framework (figure 2) that caters to the needs of a Transportation logistics business. The framework includes the Current state assessment, Future state mapping and 3-pillar approach to achieve the future state.

1. Current state assessment involves utilizing a maturity assessment survey to identify operational gaps and improvement opportunities as well as prioritizing the opportunities.
2. The improvement approach focuses on 3 key pillars -
    a. Lean Leadership - Leadership must establish a unified vision, governance framework, and communication strategy to guide I4.0 & Lean integration. Aligned leaders bridge vision and execution, ensuring that transformation is deliberate, measurable, and sustainable. Leadership teams must evolve into high performance teams, demonstrating commitment to organization’s results as well as healthy and constructive conflict.
    b. I4.0 tools provide the technological advantage for the business.
    c. Lean principles - foundational for process improvement approach
3. Future State - The disciplined application of the 3 pillars will support the business to achieve the desired future state by streamlining processes, reducing waste or non-value adding activities and meeting the cost targets.

A key finding is that the scarcity of Lean and Industry 4.0 expertise stems from a lack of decentralized problem-solving. Our framework addresses this by embedding an improvement culture into the daily work of operational teams. Crucially, we demonstrate that upskilling is most effectively achieved through the rigorous establishment of Standard Operating Procedures (SOPs), global process standardization, and application of problem-solving tools. These measures provide the baseline for digital integration, ensuring that frontline employees use I4.0 data to reinforce Lean problem-solving rather than merely reacting to new technology.

By codifying these practices into global standards, the organization transforms the Transportation Lean-I4.0 framework into a scalable, human-centric system. This approach ensures that as technology evolves, the workforce remains equipped to interpret digital outputs and eliminate waste autonomously. While validated in logistics, this framework offers immense potential for horizontal expansion into other transactional-heavy industries. Ultimately, successful Lean-I4.0 convergence depends on leveraging global standards to empower the workforce, ensuring technology catalyzes a disciplined culture of continuous improvement.

The framework pillars shown in Figure 2 operate through mutually reinforcing relationships rather than independent interactions. Lean leadership establishes governance structures, strategic alignment, and organizational readiness necessary for transformation. Lean principles provide process discipline through standardization, waste identification, and continuous improvement practices, creating stable workflows suitable for digital integration. Industry 4.0 technologies then enhance these standardized processes by enabling real-time visibility, predictive analytics, and data-driven decision-making. The interaction among the three pillars creates a cyclical improvement mechanism in which digital insights support continuous Lean improvement, while Lean governance ensures that technology adoption remains aligned with operational value creation objectives.

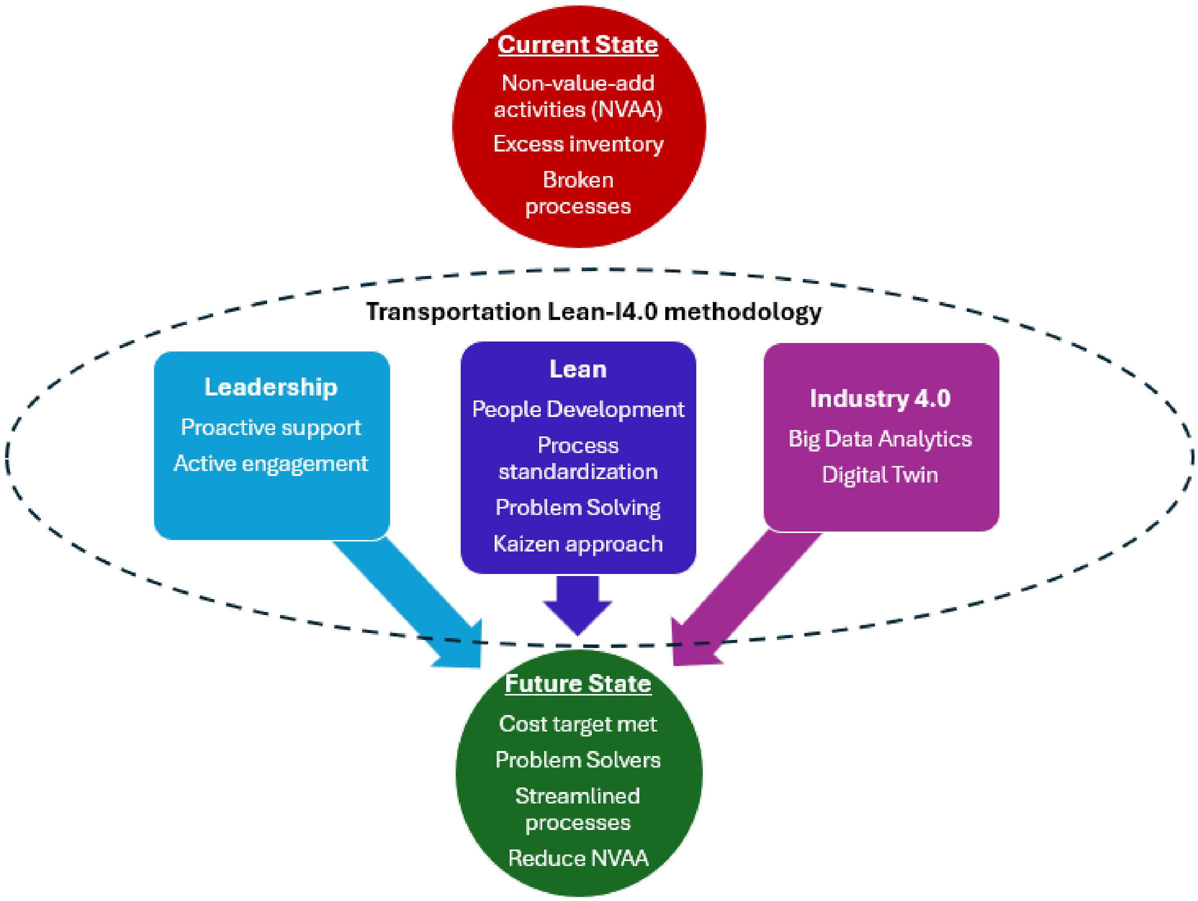

Figure 2. Transportation Lean-I4.0 Capability Integration Framework

6. Conclusion

This study contributes to Logistics 4.0 literature in three ways. First, it extends existing Lean–Industry 4.0 research by empirically demonstrating how process standardization, Lean governance, and digital technologies interact within transactional transportation logistics environments. Second, the study proposes a Transportation Lean-I4.0 capability integration framework that conceptualizes Lean practices as operational enablers of digital transformation rather than parallel improvement initiatives. Third, the findings provide case-based evidence regarding the organizational conditions required to scale Industry 4.0 adoption across globally distributed logistics operations. From a managerial perspective, the study demonstrates that sustainable digital transformation requires simultaneous investment in process discipline, leadership alignment, and workforce capability development.

The primary takeaway for practitioners in 2026 is that the transition to a "Transportation Lean-I4.0" ecosystem requires proactive leadership support to mobilize Industry 4.0 capabilities effectively. Leaders must move beyond passive endorsement to actively championing digital transformation, ensuring that technological adoption is deeply integrated with Lean operational goals. This necessitates an open and strategic approach to resource allocation, where investment is balanced between advanced digital tools and the human infrastructure, specifically the upskilling of teams and the standardization of processes. By dedicating resources to both technology and process discipline, leadership provides the necessary framework for operational teams to leverage I4.0 data for continuous improvement, ensuring that digital investments translate into a sustainable, enterprise-wide culture of excellence.

This study fulfills its research objectives by first demonstrating a scalable continuous improvement framework tailored to transactional transportation logistics, validating that Lean methodologies can be effectively adapted beyond traditional manufacturing contexts. Second, the findings show that data-driven prioritization combined with AI-enabled visibility platforms strengthens decision-making and enables measurable cost reduction outcomes. Third, the case highlights the critical role of organizational enablers including leadership sponsorship, readiness assessment, and structured change management in sustaining Lean-Industry 4.0 integration across geographically distributed operations. Collectively, the study contributes empirical evidence to Logistics 4.0 research by presenting a practical implementation model that integrates Lean discipline with digital transformation, reframing transportation logistics from a cost center into a strategic capability.

This study contributes empirical and operational insights to Lean-I4.0 literature by demonstrating how Lean governance, process standardization, and digital technologies can be integrated within transportation logistics environments. This study is subject to several limitations. First, the findings are based on a single case study within an OEM transportation logistics context, limiting statistical generalizability. Second, this study emphasizes operational implementation and qualitative organizational outcomes rather than formal statistical hypothesis testing. Although measurable operational improvements were observed, future research may apply longitudinal quantitative analysis to statistically validate the financial and operational impacts of Lean-I4.0 integration across multiple organizations.

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Biographies

Girish Kumar Gopalakrishnan is serving as North America Continuous Improvement Senior Manager at Case New Holland (CNH), Girish has led cross-plant transformation initiatives that have significantly advanced manufacturing performance, digital innovation, and cultural engagement across CNH's operations. He is a distinguished continuous improvement leader whose 15-year career reflects deep technical expertise, transformative leadership, and a sustained impact on operational excellence. He holds a Master's degree in Industrial Engineering from North Carolina State University. He was named one among top 50 business transformation leaders to follow in 2025 by Process Excellence Network. He received the 2025 Marlyn Hyde Commitment to Excellence Award from the American Society of Quality (ASQ) NE Illinois Chapter. He is an ASQ certified Master Black Belt, Black Belt and Certified Manager of Quality and Organizational Excellence. He is also a Senior member with IEOM, ASQ and Institute of Industrial Engineers (IISE). Girish is serving as the Secretary of ASQ NE Illinois Chapter, and as an Editor-in-Chief of the ASQ Lean Enterprise Division eZine Magazine.

Dr. Senthilkumar Thiyagarajan is a Supply Chain Analytics Expert working at MedTech Industry, where he focuses on supply chain analytics, digital transformation, and operational improvement initiatives. He earned his Ph.D. in Supply Chain Management from Purdue University, with research centered on supply chain resilience and digital twin applications and holds a Master of Science in Industrial Engineering from Arizona State University. His research interests include supply chain resilience, digital twins, Industry 4.0, Lean Six Sigma, quality management, and product lifecycle management. Dr. Thiyagarajan's scholarly work has been published in journals such as the International Journal of Lean Six Sigma, Total Quality Management & Business Excellence, International Journal of Productivity and Quality Management, and leading international conferences. He also serves on the Editorial Advisory Boards (EAB) of the International Journal of Lean Six Sigma (IJLSS) and the International Journal of Quality & Reliability Management (IJQRM), contributing to advancing research at the intersection of quality and supply chain innovation. A certified Six Sigma Black Belt, he brings extensive industry experience across organizations including Tesla, Schott, Cook Medical, and Zimmer Biomet, where he held roles in supply chain, quality engineering, and process improvement. In addition to his professional work, he actively contributes to professional societies such as ASQ and IISE through leadership and content development initiatives supporting Quality 4.0 and supply chain management.

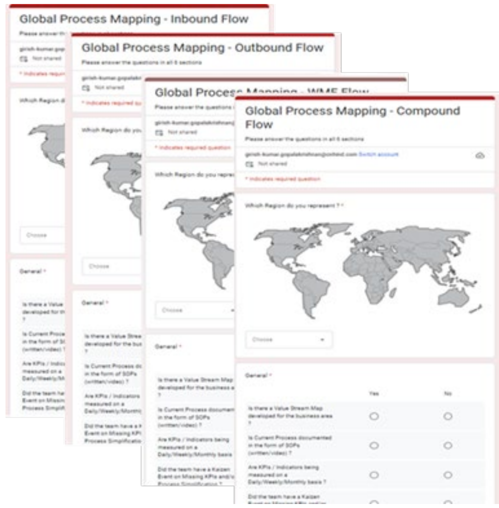
Appendix

Appendix 1. Maturity Assessment Survey

The self-assessment survey discussed in section 1 is provided as a screenshot below. An example of a Survey Question looks like - "Do you have a process to track Demurrage for containers?" with the following potential responses the SMEs can choose from -

- Yes – There exists a process
- Partial – A process exists but partially
- No – No process exists

The breakdown of the 177 questions across the different business areas is provided in figure below. The survey results were analyzed to understand the Focus Areas. In other words, the questions with 'No' and/or 'Partial' responses. Later the focus areas were ranked using a prioritization tool.


Global Process Mapping - Inbound Flow
Global Process Mapping - Outbound Flow
Global Process Mapping - Compound Flow


Regional Self-Assessment
GLOBAL PROCESS SURVEY
BUSINESS AREA
CLUSTERS
Inbound (45) *
General (5)
Forecasting (4)
Operations (11)
Analysis (13)
Economics (8)
Customs (4)
Outbound (43)
General (5)
Forecasting (5)
Operations (10)
Analysis (12)
Economics (7)
Customs (4)
WMF (37)
General (5)
Forecasting (2)
Operations (11)
Analysis (13)
Economics (6)
Compound (52)
General (5)
Forecasting (6)
Operations (23)
Analysis (12)
Economics (6)
* - (# of Survey Questions)