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# Digital transformation of logistics business processes in the agro-industrial complex: a strategic approach to sustainable development


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## Abstract

This article proposes a structured theoretical and analytical approach to assessing digital transformation (DT) as a strategic program for implementing digital changes focused on BPM for business processes in the field of logistics. DT is viewed as the synergy of necessary sets of digital tools. It is proposed to divide the transformation into three management levels and apply two practical implementation tools: a set of concise indicators and a phased roadmap. The findings are threefold. First, the proposed three-layer evaluation model clarifies managerial responsibilities by distinguishing strategic governance (alignment with ISO 9001/22000/14001, UN SDGs, and explicit data-governance and cybersecurity policies), tactical capabilities (deployment of WMS/TMS, IoT telemetry, AI-based forecasting for planning and routing, blockchain mechanisms for trust, and Big-Data analytics for decision support), and operational execution (PDCA-driven routines, role clarity, and partner onboarding through open APIs). Second, the indicator suite operationalizes the model across five dimensions - readiness and governance, process performance, transparency and trust, sustainability, and inclusion and capability – capturing, among others, connectivity and interoperability, MAPE, OTIF, order-to-delivery lead time, inventory turns, traceability coverage, data-integrity incidents, waste reduction, SME participation, training intensity, and digital literacy. Third, the roadmap sequences investments from foundations through core digitization and transparency at scale to full sustainability integration, thereby avoiding fragmented, technology-only rollouts. Overall, the framework translates generic managerial levers into actionable capabilities and KPIs that raise reliability, reduce losses and costs, strengthen transparency, and embed sustainability goals. It is sector-agnostic in illustration yet directly applicable to complex, multi-actor logistics networks, and it sets up empirical validation through case studies and surveys.



**Keywords:** digital transformation, business process management, logistics, agro-industrial complex, sustainability

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## Introduction

Logistics organizations operate in increasingly volatile environments characterized by demand variability, supply-side shocks, regulatory pressure, and rising expectations for transparency and sustainability. Digital transformation (DT) is widely promoted as a remedy, yet in practice, many initiatives remain tool-centric, fragmented across functions, and weakly connected to business process management (BPM) and governance. As a result, firms often accumulate technologies – warehouse and transport systems, sensors, analytics - without establishing a managerial architecture that converts data and automation into reliable performance, measurable value, and progress toward sustainability goals.

From a management perspective, three gaps are recurrent. First, there is a governance gap: the absence of explicit alignment between DT programs and process/quality standards (e.g., ISO 9001/22000/14001), data-governance policies, and cybersecurity baselines. Second, there is a capability gap: organizations struggle to translate technologies such as WMS/TMS, IoT, AI-based forecasting, blockchain, and Big Data analytics into coherent process capabilities for planning, execution, and control across multi-actor networks. Third, there is a measurement gap: firms lack a concise indicator suite that links DT investments to outcomes such as reliability (OTIF), lead times, inventory turns, traceability coverage, emissions intensity, and inclusion of smaller partners.

This study addresses these gaps by reframing DT not as a set of discrete tools but as a BPM-led change program for logistics business processes. The research develops a structured theoretical-analytical approach that:

a) Specifies a three-layer evaluation model distinguishing strategic governance, tactical capabilities, and operational execution.

b) Operationalizes the model through a compact indicator suiting readiness and governance, process performance, transparency and trust, sustainability, and inclusion and capability.

c) Proposes a phased roadmap that sequences investments from foundational enablers to transparency at scale and, ultimately, sustainability integration.

## Literature Review

A growing body of management research argues that digital transformation (DT) in logistics delivers results only when embedded in business process management (BPM) - that is, when technologies are governed by clear process architectures, roles, controls, and continuous-improvement routines. Bibliometric reviews mapping DT–BPM scholarship reports rapid growth but also a persistent split between tool-centric studies and work that theorizes managerial governance and measurement, signaling the need for integrative, process-oriented frameworks (Truong, Nguyen-Duc, & Van, 2023; Berniak-Woźny & Szelągowski, 2024).

Within "Logistics 4.0," recent evidence charts a shift from exploratory pilots to more mature deployments of connected systems (Risberg A, 2022). A large bibliometric analysis of 2,680 publications shows IoT applications concentrating on visibility (track-and-trace, condition monitoring), event-driven control, and risk management - yet also highlights uneven interoperability and limited attention to the managerial routines that convert sensor data into decisions (Zrelli & Rejeb, 2024).

Artificial intelligence (AI) is increasingly positioned as a planning and orchestration layer across forecasting, routing, and capacity allocation. A recent synthesis focused on sustainability criteria documents measurable logistics improvements when AI models are embedded in decision loops, while also underscoring data-quality, explainability, and KPI-alignment challenges that remain underdeveloped in managerial terms (Chen et al., 2024, Lysenko et al., 2023).

Blockchain research in supply networks emphasizes transparency, provenance, and fraud reduction. Systematic reviews from 2023–2024 find growing convergence with other Industry 4.0 tools but note that many studies stop at technical feasibility, offering limited guidance on contractual alignment, data stewardship, and scaling across multi-actor networks - precisely the domains where BPM and governance must lead (Ellahi et al., 2023; Ellahi, Hussain, Kamboh, Alshammari, & Alzahrani, 2024).

Parallel standards work clarifies data semantics for inter-organizational traceability. The GS1/FSMA Rule 204 toolkit codifies "Critical Tracking Events" (CTEs) and "Key Data Elements" (KDEs) and recommends EPCIS-based data capture and exchange, providing a lingua franca for interoperable visibility - yet these specifications are rarely operationalized in managerial evaluation models or indicator suites (GS1 US, 2024; GS1 US, 2025).

Sectoral syntheses on cold-chain logistics similarly underline that performance gains less on isolated sensors and more on how data, processes, and roles are governed end-to-end (alert ownership, escalation thresholds, auditability), again pointing to the BPM layer as the missing link between technology and outcomes (Mustafa, Navaranjan, & Demirovic, 2024).

Across these streams, four gaps recur:

a) a tool-centric bias with insufficient specification of governance, roles, and PDCA routines;

b) fragmented measurement, with few compact suites linking DT investments to reliability (e.g., OTIF), lead times, inventory turns, traceability coverage, and sustainability metrics (Lysenko S., 2024);

c) interoperability and data-stewardship gaps, despite available standards such as EPCIS/CTE/KDE;

d) a lack of phased roadmaps that de-risk adoption;

e) the present study addresses these gaps by proposing a three-layer evaluation model (strategic governance, tactical capabilities, operational execution), a concise indicator suite, and a sequenced roadmap that connects technologies to capabilities, capabilities to KPIs, and KPIs to strategic objectives.

## Methodology of Research

This study adopts a conceptual-analytical design oriented to management and BPM. The unit of analysis is the logistics business process (planning, storage, transport, last mile/service, and supporting data/quality flows). The objective is to construct:

a) a three-layer evaluation model (strategic governance, tactical capabilities, operational execution);

b) a concise indicator suite linking DT to outcomes (reliability, cost, transparency, sustainability, inclusion);

c) a phased roadmap that sequences investments and governance decisions.

We synthesized peer-reviewed management and logistics literature, standards and guidance (e.g., ISO 9001/22000/14001; GS1/EPCIS concepts), and high-quality policy/industry reports (used only to clarify definitions and metrics). Narrow, purely technical prototypes without managerial evaluation were excluded. When foundational sources were necessary (definitions, formulas), they were included in anchor measurement.

We derived the four-phase pathway by aligning (a) dependency structures among capabilities (e.g., data governance before traceability at scale), (b) feasibility under typical constraints (connectivity, skills, partner readiness), and (c) marginal impact on core outcomes. The resulting sequence: Foundations – Core Digitization – Transparency at Scale – Sustainability Integration – minimizes fragmentation and lock-in.

## Research Questions

This study frames digital transformation (DT) as a BPM-led change program and investigates how governance, capabilities, and execution translate into measurable logistics outcomes. The questions below guide the evaluation model, indicator suite, and phased roadmap introduced later in the paper (Table 1).

RQ1 – Governance effectiveness. How does alignment with process/quality and environmental standards (e.g., ISO 9001/22000/14001), explicit data-governance and cybersecurity policies influence DT program effectiveness in logistics networks?

RQ2 – Capability-performance link. Which DT capabilities (e.g., WMS/TMS, IoT telemetry, AI-based forecasting/routing, blockchain for traceability, Big-Data analytics) contribute most to improvements in process performance (e.g., OTIF, order-to-delivery lead time, inventory turns) after controlling for baseline process maturity?

RQ3 – Interoperability and transparency. To what extent does interoperability (open APIs, standards-based data exchange) mediate the relationship between DT capabilities and transparency/trust outcomes (traceability coverage, data-integrity incidents, share of smart-contract transactions) across multi-actor networks?

RQ4 – Sustaining gains through routines. What is the effect of embedding continuous-improvement routines (PDCA/Kaizen cycles, S&OP cadences, audit trails) on the persistence of performance gains from DT over time?

RQ5 – Inclusion and capability building. How do partner inclusion and capability-building investments (SME/co-op onboarding, training intensity, digital-literacy programs) moderate the impact of DT on network-wide outcomes and reduce performance variance across partners?

RQ6 – Sequencing and risk. Which sequence of interventions maximizes benefit-cost and minimizes risk of fragmentation – does the proposed Foundations – Core Digitization – Transparency at Scale – Sustainability Integration roadmap outperform alternative sequences?

Table 1. Operationalization and measurement (for empirical validation)

| Construct | Operational definition | Primary indicators | Typical data sources | Evaluation notes |
|---|---|---|---|---|
| Governance alignment | Formal adoption of ISO-aligned process/food-safety/environmental controls; approved data & security policies | Governance index (composite), cybersecurity posture, audit pass rate | Policy docs, audit reports, risk logs | Used as predictor in RQ1 |
| DT capabilities | Deployed systems and their use in core processes (WMS/TMS, IoT, AI/ML, blockchain, analytics) | Capability coverage (% nodes/processes), automation ratio, event capture rate | System inventories, WMS/TMS logs, IoT streams | Predictor in RQ2-RQ3 |
| Interoperability | Standards-based exchange and partner connectivity | % partners via open APIs, standards adoption score, E2E data completeness | API gateways, integration catalogs, traceability records | Mediator in RQ3 |
| Process performance | Reliability and efficiency of flows | OTIF %, order-to-delivery lead time (P50/P90), inventory turns | WMS/TMS KPIs, transport logs | Outcome in RQ2-RQ6 |
| Transparency & trust | Visibility and data integrity across the chain | Traceability coverage %, data-integrity incidents/quarter, smart-contract share % | Provenance/quality records, blockchain ledgers, incident registers | Outcome in RQ3 |
| Sustainability | Environmental and waste metrics tied to operations | Energy intensity (kWh/ton-km), $CO_2e$/ton-km, spoilage/waste % | Telematics, fuel/energy bills, quality losses | Outcome in RQ6 |
| Inclusion & capability | Breadth and depth of partner enablement | SME/co-op participation %, training hours/FTE, digital-literacy score | HR/L&D records, partner registries | Moderator in RQ5 |
| Routines & persistence | Institutionalized continuous-improvement practices | PDCA cadence adherence, corrective-action closure time, audit trail completeness | CI boards, action logs | Predictor in RQ4 |

*Source: Authors' compilation based on (Berniak-Woźny & Szelągowski, 2024; Chen, Men, Fuster, Osorio, & Juan, 2024; Ellahi, Wood, & Bekhit, 2023, 2024; Lysenko, 2024; Lysenko, Makovoz, & Perederii, 2023; Mustafa, Navaranjan, & Demirovic, 2024; Risberg, 2022; Truong, Nguyen-Duc, & Van, 2023; Zrelli & Rejeb, 2024).*

These research questions and operational definitions directly bridge the evaluation model (governance-capabilities-execution) with the indicator suite and roadmap presented in the Results section, ensuring that managerial levers can be tested against measurable outcomes.

## Results

This section presents the core contribution:

a) a three-layer evaluation model that clarifies managerial responsibilities for digital transformation (DT) in logistics;

b) a concise indicator suits the model;

c) a phased roadmap that sequences governance and technology decisions to avoid fragmented, tool-centric rollouts.

*1. Three-layer evaluation model.*

*1.1 Strategic governance (board/executive/enterprise BPM).*

Purpose: Anchor DT in process governance, standards, and data policy.
Core responsibilities:

- Standards alignment: Embed ISO 9001/22000/14001 requirements into process architecture, audit cadence, and risk controls.
- Data governance & cybersecurity: Define ownership, access, retention, interoperability rules (e.g., EPCIS/GS1 concepts for traceability), and a minimum-security baseline.
- Target setting & accountability: Approve target values for reliability (e.g., OTIF), cost, transparency (traceability coverage), sustainability ($CO_2$e/ton-km), and inclusion (SME onboarding).
- Portfolio management: Prioritize DT initiatives by value/risk; ensure dependencies are respected (e.g., data governance before cross-partner traceability).

Decision artefacts: Process architecture & RACI, policy set (data/cyber), KPI tree and targets, investment roadmap, risk register.

*1.2 Tactical capabilities (process owners / functional leaders)*

Purpose: Translate technologies into repeatable capabilities for planning, execution, and control.
Capability map (illustrative, adaptable):

- Planning & orchestration: S&OP cadence, AI-based forecasting, capacity/routing optimization.
- Storage & inventory: WMS/EMS + IoT for condition monitoring (e.g., temperature/humidity where relevant), lot/FEFO control, cycle counting.

- Transport management: TMS + telematics, slot booking, dynamic routing, dwell-time control.
- Last-mile & service: Event-driven workflows, service-level management, customer/partner portals.
- Compliance & traceability: Blockchain or signed event chains (where justified), EPCIS-style event capture, recall drills.

Controls: Thresholds and alerts tied to KPIs; audit trails; playbooks for incident response.

*1.3 Operational execution (line management / CI teams)*

Purpose: Run processes reliably and improve them continuously.
Routines: PDCA/Kaizen boards, daily/weekly KPI reviews, corrective actions and closure SLAs, automated health checks for data pipelines and integration endpoints.

*2. Indicator suite (operationalization)*

A compact set of indicators links capabilities to managerial outcomes. Each indicator includes a definition, preferred data source, and review cadence (Table 2).

Table 2. Core KPI suite for BPM-led digital transformation in logistics

| Dimension | Indicator (definition) | Primary data source | Review cadence |
|---|---|---|---|
| Readiness & governance | Interoperability index (% partners via open APIs; standards adoption score) | API gateway, integration registry | Monthly |
| | Cybersecurity posture (controls implemented; incidents/quarter) | Risk register, SOC reports | Quarterly |
| Process performance | OTIF (%) = (Deliveries on time and in full ÷ Total deliveries) × 100 | WMS/TMS | Weekly/Monthly |
| | Order-to-delivery lead time (P50/P90, hours/days) | WMS/TMS | Weekly |
| | MAPE (%) for forecasts | Planning/analytics logs | Monthly |
| | Inventory turns = COGS ÷ Avg. inventory | Finance/ERP | Monthly |
| Transparency & trust | Traceability coverage (%) = Lots/SKUs with end-to-end provenance ÷ Total | Provenance/quality system | Monthly |
| | Data-integrity incidents (per quarter) | Incident register | Quarterly |
| Sustainability | Emissions intensity (kg $CO_2e$ ÷ ton-km) | Telematics/fuel-energy data | Monthly/Quarterly |
| | Loss/waste rate (%) (spoilage/processing losses ÷ throughput) | Quality/WMS | Monthly |
| Inclusion & capability | SME/partner onboarding (%), training hours/FTE, digital-literacy score | Partner registry; L&D | Quarterly |

*Source: Authors' compilation based on GS1 US (2024, 2025); International Organization for Standardization (2024a, 2024b, 2024c); Ellahi, Wood, and Bekhit (2023, 2024); Mustafa, Navaranjan, and Demirovic (2024); Berniak-Woźny and Szelągowski (2024); Truong, Nguyen-Duc, and Van (2023).*

### *3. Phased roadmap*

The roadmap sequences investments to respect dependencies, spread risk, and maintain a line of sight from technology to KPIs (Table 3).

Table 3. Phased roadmap for BPM-led digital transformation in logistics

| Phase | Objective | Key actions | Exit criteria |
|---|---|---|---|
| Phase 1. Foundations | Establish governance and data prerequisites. | Approve data & cybersecurity policies.<br>Define process architecture and KPI targets.<br>Deploy a minimal viable cloud WMS/TMS.<br>Stand up the integration gateway.<br>Baseline OTIF, lead time, traceability, and emissions. | Policy set approved.<br>Golden data objects are defined.<br>KPI baselines published.<br>First integrations live. |
| Phase 2. Core Digitization | Embed event capture and decision support in priority flows. | Roll out IoT event streams were material.<br>Enable AI forecasting and routing.<br>Automate exception workflows.<br>Institute PDCA cadences.<br>Complete first ISO audit cycle aligned to process controls. | Event capture rate ≥ X%.<br>Forecast MAPE improvement ≥ Y%.<br>OTIF +Δ vs. baseline.<br>Audit non-conformities addressed. |
| Phase 3. Transparency at Scale | Achieve interoperable, cross-partner visibility. | Expand open APIs.<br>Implement EPCIS-style event models.<br>Pilot blockchain/signed events where trust or recall obligations justify.<br>Formalize recall drills and incident post-mortems. | Traceability coverage ≥ X%.<br>Data-integrity incidents ↓.<br>Partner connectivity ≥ Y%. |
| Phase 4. Sustainability Integration | Embed environmental metrics and cost–carbon optimization. | Operationalize emissions accounting (kg $CO_2$e/ton-km).<br>Integrate energy/fuel telemetry with routing.<br>Add loss/waste dashboards.<br>Include sustainability targets in S&OP and vendor scorecards. | Emissions intensity ↓ by X%.<br>Waste/loss rate ↓ by Y%.<br>KPI tree includes sustainability and is reviewed at executive cadence. |

*Source: Authors' synthesis based on Berniak-Woźny & Szelągowski (2024); Truong, Nguyen-Duc, & Van (2023); International Organization for Standardization (2024a, 2024b, 2024c); Zrelli & Rejeb (2024); Chen, Men, Fuster, Osorio, & Juan (2024); Ellahi, Wood, & Bekhit (2023, 2024); Mustafa, Navaranjan, & Demirovic (2024).*

## *4. Managerial implications and risk controls*

−From tools to governance: Success depends on explicit ownership (who acts on which alert), not just on sensors or models.

−Measure what you manage: The indicator suite is intentionally small; expand only with clear decision rights.

−De-risk interoperability: Adopt standards early to avoid costly rewrites; treat integration quality as a first-class KPI.

−Sustain gains: Lock improvements through routines (cadences, audits, closure SLAs), not one-off projects.

−Equity and scale: Partner onboarding and training reduces variance across the network and increase the persistence of gains.

Figure 1 consolidates the three deliverables of the Results section into one management-oriented view:

−First, it instantiates the three-layer evaluation model by showing how strategic governance (standards, data and cybersecurity policies, target setting) enables tactical capabilities (WMS/TMS, IoT, AI/forecasting, blockchain, analytics) that are executed through operational routines (PDCA, audits, incident playbooks) across core logistics processes.

−Second, it cross-references the indicator suite by placing each family of KPIs where it is produced and used: process performance (e.g., OTIF, lead time, inventory turns) at execution nodes; transparency & trust (traceability coverage, data-integrity incidents) at interoperability and provenance touchpoints; readiness & governance (interoperability index, cyber posture) at the policy and architecture layer; sustainability ($CO_2e$ per ton-km, loss/waste rate) alongside transport and storage flows; and inclusion & capability (SME onboarding, training intensity) at partner interfaces.

−Third, the diagram encodes the logic of the phased roadmap: the left-to-right flow from drivers and processes to digital interventions and outcomes reflects the sequencing of Foundations (governance and data prerequisites), Core Digitization (event capture and decision support), Transparency at Scale (standards-based interoperability and traceability), and Sustainability Integration (cost-carbon optimization and waste reduction).

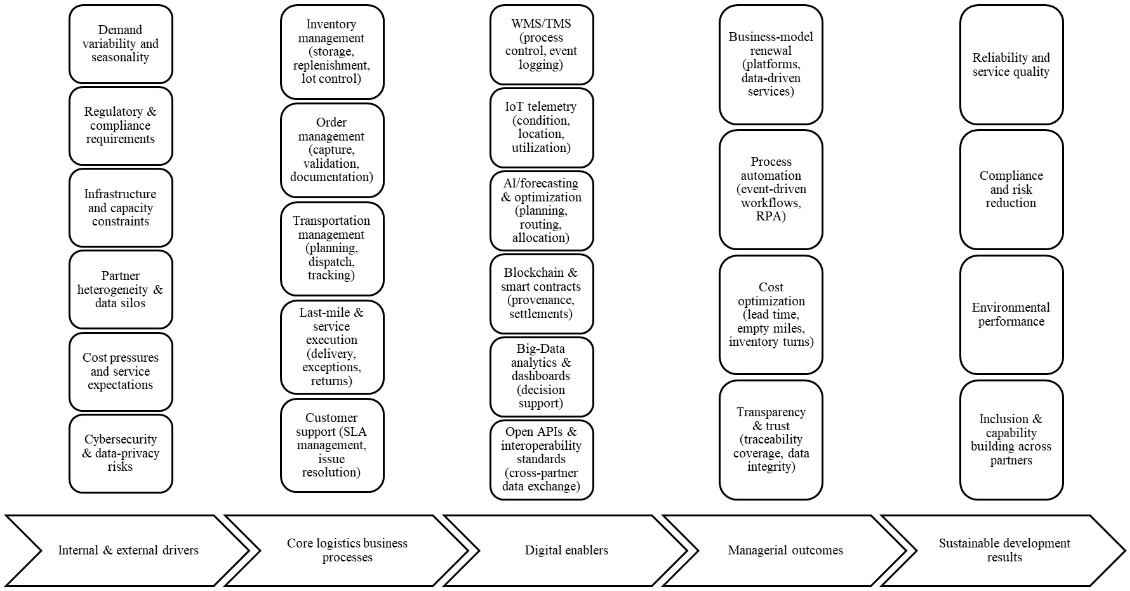


Figure 1. Digital transformation of logistics business processes in the agro-industrial complex: a strategic approach to sustainable development

*Source: authors elaboration*

## Conclusion

In this research, the authors justified the need to consider digital transformation (DT) in logistics both as a system for implementing digital technologies and as a management program based on BPM. It contributes three integrated artefacts. First, the three-layer evaluation model clarifies responsibilities across strategic governance, tactical capabilities, and operational execution, ensuring that technologies are embedded in process architecture, standards, and data/cyber policies. Second, a concise indicator suite links capabilities to outcomes - reliability (OTIF, lead time, inventory turns), transparency and trust (traceability coverage, data-integrity incidents), readiness and governance (interoperability, cyber posture), sustainability ($CO_2e$ per ton-km, loss/waste), and inclusion and capability (SME onboarding, training intensity). Third, a phased roadmap sequences decisions: Foundations - Core Digitization – Transparency at Scale – Sustainability Integration, so that investments respect dependencies and avoid fragmented, tool-centric adoption. Managerially, the framework provides a line of sight from drivers – interventions – capabilities – KPIs – strategic objectives. By treating interoperability and data quality as first-class objects, the approach reduces integration risk and increases the persistence of performance gains. Embedding sustainability metrics alongside operational KPIs enables cost-carbon optimization instead of parallel, disconnected reporting. For practitioners, immediate use cases include:

a) stress-testing ongoing DT portfolios against the model's governance prerequisites;

b) pruning dashboards to the proposed indicator core with clear ownership and escalation thresholds;

c) aligning annual plans to the roadmap's exit criteria, using P50/P90 reporting to expose tail risks.

Future analyses should apply the indicator suited in multi-case settings, examine persistence of gains under different continuous-improvement regimes, and refine governance metrics for data stewardship and cybersecurity. Extending the framework to varied regulatory environments and partner structures will further test its generalizability.

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Abbreviations
AIC - Agro-industrial complex.
AI - Artificial intelligence.
API - Application Programming Interface.
BPM - Business Process Management.
CI - Continuous Improvement.
DT - Digital Transformation.
E2E - End-to-End.
EMS - Environmental Monitoring System.
ERP - Enterprise Resource Planning.
FEFO - First Expired, First Out.
FSMA - Food Safety Modernization Act.
FTE - Full-Time Equivalent.
GS1 - Global Standards One.
IoT - Internet of Things.
KDE - Key Data Element.
KPI - Key Performance Indicator.
MAPE - Mean Absolute Percentage Error.
ML - Machine Learning.
OTIF - On Time, In Full.
PDCA - Plan–Do–Check–Act.
P50/P90 - 50th/90th percentile (statistical service-level metrics).
RACI - Responsible, Accountable, Consulted, Informed (roles matrix).
S&OP - Sales and Operations Planning.

SDGs - United Nations Sustainable Development Goals.
SLA - Service Level Agreement.
SME - Small and Medium-sized Enterprise.
SOC - Security Operations Center.
TMS - Transport Management System.
WMS - Warehouse Management System.