Digital Transformation and Supply Chain Efficiency: A Synthesis of Evidence on Technologies, Capabilities and Sustainable Performance

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Abstract

Digital transformation (DT) has moved from a discretionary investment to a core requirement for firms that manage complex, multi-tier supply chains. This paper synthesises recent evidence on how DT affects supply chain efficiency and, more broadly, sustainable supply chain performance across the economic, environmental and social dimensions of the triple bottom line. It draws on a PRISMA-based systematic literature review of 625 peer-reviewed articles published between 2020 and 2025 and indexed in Scopus, together with the primary studies that review cites. The synthesis shows that DT improves efficiency mainly through real-time visibility, data-driven planning and cross-organisational integration, but that these gains are contingent rather than automatic. Efficiency outcomes depend on the technologies deployed (integrated IoT, blockchain, AI and big data analytics rather than stand-alone systems), on organisational capabilities (digital leadership, digital culture, dynamic capabilities and collaboration) and on environmental conditions (regulation, turbulence and stakeholder pressure). Evidence on social outcomes is thinner and more ambivalent, with concerns about digital divides, job displacement and data privacy. The paper proposes an integrative conceptual framework, advances four propositions, and outlines implications for managers, policymakers and future research. A 15-item questionnaire is also presented, and its analysis is demonstrated on a 120-record synthetic dataset that is identified as such throughout and is not empirical evidence.

Keywords: digital transformation; supply chain efficiency; sustainable supply chains; triple bottom line; organisational capabilities; systematic literature review

1. Introduction

The digital economy has reshaped how goods are sourced, produced, distributed and sold. Digital transformation, understood here as the integration of digital technologies into business processes (Rêgo et al., 2024), now sits at the centre of how firms compete and how they organise their supply chains. Technologies such as social media, artificial intelligence (AI), big data analytics, cloud computing, the Internet of Things (IoT) and smart devices allow firms to participate in, and benefit from, the dynamics of the digital economy (Yang & Lin, 2025).

The COVID-19 pandemic accelerated this shift. Digital adoption moved from a strategic option to a survival mechanism: agricultural entrepreneurs in China turned to e-commerce and social media to keep selling during lockdowns (Cao et al., 2024), and Malaysian food operators rapidly integrated online delivery platforms into their operations (Jahari et al., 2022; Kee et al., 2025). At the macro level, remote work, e-commerce and digital payments became everyday practice within a few months.

For supply chains, the question is not only whether digital tools make operations faster or cheaper. Supply chain efficiency, meaning the ability to deliver required service levels with fewer resources, less time and less waste, is

increasingly judged alongside environmental and social performance. Digital tools allow supply chain partners to monitor carbon emissions collaboratively, optimise energy use and support circular production systems. AI-based models can forecast energy demand and emissions, detect process anomalies and enable predictive maintenance (Uddin, 2024; Ameh, 2024). Digital monitoring of workplace conditions can also strengthen health and safety.

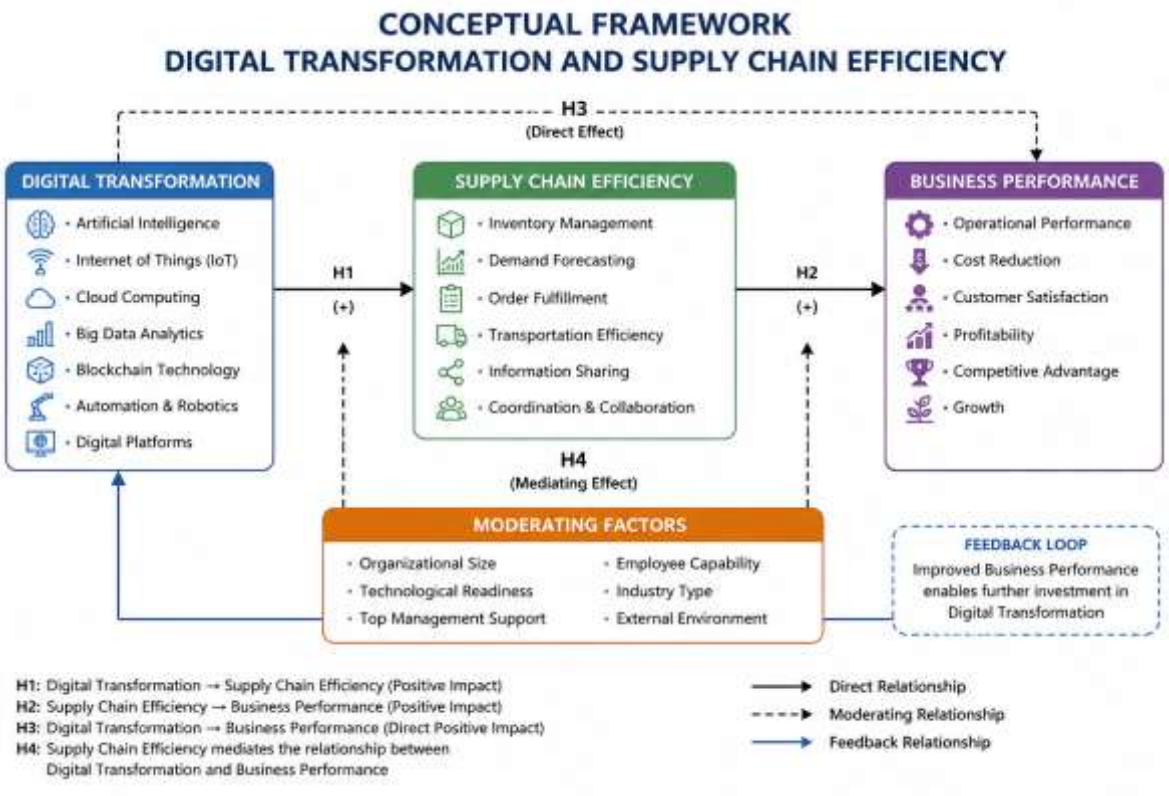
Yet many firms struggle with the transition. Reported barriers include resistance to change (Abdallah et al., 2021), incompatible corporate culture (Brunetti et al., 2020), limited technological capability (Tian & Ou, 2024) and financial constraints (Han & Zheng, 2022). Studies commonly examine these barriers in isolation or for a single technology, so the evidence remains scattered across disciplines, industries and methods. As a result, it is difficult to say when and why digital transformation raises supply chain efficiency and whether it does so without sacrificing social or environmental outcomes.

This paper addresses that gap. It consolidates recent evidence to answer three research questions:

- RQ1: What thematic clusters and research trends characterise the literature on digital transformation and sustainable supply chains?
- RQ2: How does digital transformation influence supply chain efficiency and wider sustainable performance across the triple bottom line?
- RQ3: Which technologies, organisational capabilities and environmental conditions make digital transformation effective?

The contribution is an integrative framework that treats digital transformation as a socio-technical process whose efficiency and sustainability effects are contingent on enabling conditions, together with a set of propositions to guide empirical work.

Conceptual Framework



2. Conceptual Background

2.1 Evolution of digital transformation research

Early work conceptualised digital transformation as the digitisation and automation of business operations, with digital tools supporting efficiency, cost reduction and productivity (Westerman et al., 2014; Fitzgerald et al., 2013). Later scholarship repositioned it as a strategic and organisational phenomenon that reshapes business models, value-creation mechanisms and inter-organisational relationships (Baiyere et al., 2020; Zoppelletto et al., 2023). On this view, transformation requires structural reconfiguration, organisational change and capability development, rather than merely installing new technology.

The pandemic marked a further inflection point. Research increasingly links digital transformation to resilience, economic sustainability and long-term performance (Alghamdi & Alghamdi, 2022; Arora et al., 2025), and treats it as a strategic response to turbulence, uncertainty and disruption.

Table 1 summarises these phases.

Table 1. Phases in the evolution of digital transformation research

Phase	Conceptualisation	Main focus	Key sources
Early digitisation	Digitisation and automation of business operations; digital tools as supporting tools	Operational efficiency, cost reduction, productivity	Westerman et al. (2014); Fitzgerald et al. (2013)
Strategic and organisational	Reshaping of business models, value creation and inter-organisational relationships	Structural reconfiguration, organisational change, capability development	Baiyere et al. (2020); Zoppelletto et al. (2023)
Post-pandemic	Strategic response to turbulence, uncertainty and disruption	Resilience, economic sustainability, long-term performance, societal impact	Alghamdi & Alghamdi (2022); Arora et al. (2025)

Source: synthesised from the studies cited in Section 2.1.

2.2 Supply chain efficiency in a digital setting

Traditional supply chains often run on fragmented data, limited visibility and reactive decisions. Digitalisation allows real-time monitoring, predictive planning and integrated coordination across supply chain stages (Karuppiah et al., 2024). Because supply chains involve many stakeholders, coordination depends on information sharing, which digital transformation strengthens (Liu & Chi, 2024). Technologies such as IoT, blockchain, AI and data analytics improve transparency, traceability and real-time monitoring (Tavana et al., 2022). Efficiency in this sense covers production planning, logistics routing, inventory and demand management, and the speed and accuracy of information flow between partners.

Table 2 contrasts traditional and digitally transformed supply chains on the dimensions that matter most for efficiency.

Table 2. Traditional versus digitally transformed supply chains

Dimension	Traditional supply chain	Digitally transformed supply chain
Data	Fragmented data across partners	Integrated, real-time data shared across partners
Visibility	Limited visibility along the network	Real-time monitoring, transparency and traceability

Dimension	Traditional supply chain	Digitally transformed supply chain
Decision-making	Reactive	Predictive and data-driven planning
Coordination	Siloed information systems	Integrated coordination powered by information sharing
Sustainability tracking	Tracking and tracing difficult without real-time data	Real-time monitoring of emissions, resources and waste

Source: synthesised from Karuppiah et al. (2024), Liu and Chi (2024) and Tavana et al. (2022).

2.3 Digital transformation and sustainability

A growing body of work links digital technologies to environmental, economic and social objectives (Mohaghegh et al., 2025; Li, 2022). Digital tools enable real-time tracking of emissions, better traceability and data-driven decisions. In EU countries, digital transformation has been linked to the acquisition of green knowledge, eco-friendly innovation and more efficient resource allocation (Wu & Li, 2023). Social sustainability outcomes, such as reduced disparities in education, healthcare and income, have received less attention (Wang et al., 2023).

The relationship is not uniformly positive. Regions with different digital infrastructure and social conditions benefit unequally (Nosratabadi et al., 2023), and algorithm-dependent technologies such as AI may introduce privacy concerns and bias that undermine equitable social outcomes.

2.4 Theoretical lenses

Three theoretical perspectives recur in the evidence reviewed. The resource-based view explains why technology alone rarely delivers advantage: value arises when firms combine digital assets with complementary human and organisational resources. Dynamic capabilities theory explains how firms sense change, seize opportunities and reconfigure processes as conditions shift. Resource orchestration theory emphasises how managers bundle and deploy resources. Together they imply that the efficiency effect of digital transformation is mediated by capabilities such as agility, integration and alignment, rather than flowing directly from technology adoption.

Table 3 sets out how each lens frames the efficiency question.

Table 3. Theoretical lenses used to explain digital transformation outcomes

Theory	Core idea	Implication for supply chain efficiency
Resource-based view	Value arises when firms combine digital assets with complementary human and organisational resources	Technology alone rarely delivers advantage
Dynamic capabilities	Firms sense change, seize opportunities and reconfigure processes as conditions shift	Agility and process reconfiguration mediate the effect of digital transformation
Resource orchestration	Managers bundle and deploy resources to create capabilities	Digital technologies must be reconfigured and orchestrated to yield positive outcomes

Source: synthesised from the theoretical grounding of the reviewed studies (Section 4.2.1).

3. Methodology

This paper is a literature-based synthesis. Its evidence base is a systematic literature review (SLR) of digital transformation and sustainable supply chain research that followed the PRISMA guidelines for transparency, rigour and reproducibility (Liberati et al., 2009), supplemented by the primary studies cited in that review.

3.1 Evidence base and selection criteria

The underlying review searched Scopus, selected for its broad coverage of abstracts across fields (Marikyan et al., 2019). The search combined four concept groups using Boolean operators: digital transformation or digitalisation; supply chain, logistics, distribution or procurement; sustainability, sustainable, eco-friendly or green; and performance, efficiency, effectiveness or productivity. Table 4 summarises the criteria and Table 5 lists the search string components.

Table 4. Search and selection criteria of the underlying review

Element	Specification
Database	Scopus
Period	2020 to 2025 (2020 treated as a structural break because of COVID-19)
Document type and language	Peer-reviewed journal articles written in English; conference papers, book chapters and non-academic publications excluded
Subject area	Business, Management and Accounting
Inclusion	Studies on the role of digital transformation or related technologies in supporting sustainability across environmental, social or economic dimensions
Exclusion	Purely technical digital transformation without sustainability implications; studies without full text, with insufficient methodological detail or without clear focus
Final sample	625 articles retained after screening and eligibility assessment

Source: Chieh and Mohezar (2025), reconstructed from the review protocol.

Table 5. Search string components

Concept group	Search terms (combined with OR)	Combination
Digital transformation	"digital transformation"; "digitalization"	Groups joined with AND
Supply chain	"supply chain"; "logistics"; "distribution"; "procurement"	Groups joined with AND
Sustainability	"sustainability"; "sustainable"; "eco-friendly"; "green"	Groups joined with AND
Performance	"performance"; "efficiency"; "effectiveness"; "productivity"	Groups joined with AND

Source: Chieh and Mohezar (2025).

3.2 Screening and extraction

Titles and abstracts were screened by two researchers, followed by full-text review. Data were recorded in an evidence table, duplicates were removed, and extraction and quality assessment were carried out independently by two researchers

to reduce error. Studies were then grouped by keywords, research type, objectives and conclusions to identify thematic clusters.

Table 6. Screening and selection stages

Stage	Activity	Conducted by
Round 1	Titles and abstracts screened against the inclusion and exclusion criteria	Two researchers
Round 2	Criteria applied according to the research questions; results organised in a table; studies without full text, with insufficient methodological detail or without clear focus removed	Two researchers
Round 3	All results read and integrated into a single document	A single researcher
Extraction	Data recorded in an evidence table (Excel); duplicate entries removed; quality assessment performed	Two researchers, independently
Final sample	625 articles retained for synthesis and thematic analysis	Not applicable

Source: Chieh and Mohezar (2025), reconstructed from the review protocol.

3.3 Analytic approach of this paper

This paper re-organises that evidence around supply chain efficiency. Findings were arranged under the three research questions, and cross-cutting patterns were used to build the conceptual framework in Section 6. Because the paper synthesises published results rather than running a new database search, its conclusions inherit the scope and limitations of the underlying review, which are discussed in Section 8.

3.4 Survey instrument

To support empirical testing of the propositions in Section 6, a structured questionnaire was designed alongside the literature synthesis. It contains 15 closed-ended items grouped into five constructs that mirror the review's findings: real-time visibility and tracking, process automation and efficiency, data analytics and AI in decision-making, agility and resilience, and integration and collaboration. The full instrument is reproduced in Appendix A (Tables A1 and A2).

The instrument was applied to a file of 120 records. Every record in the file carries the status label SYNTHETIC_SAMPLE_NOT_REAL_RESPONSE, so the data were generated for illustration and were not collected from practitioners. Section 5 reports the analysis on that basis. The results demonstrate how the instrument and the analysis work, but they are not evidence about real organisations and should be replaced with data from real respondents before any empirical claim is made.

Twelve items use five-point ordinal response scales, for example from very high to very low, or from "to a very great extent" to "not at all". Three items (Questions 2, 5 and 15) ask respondents to choose the single technology or process that matters most and are therefore nominal. Responses are analysed with descriptive statistics (frequencies, percentages, means and standard deviations), construct scores and non-parametric tests suited to ordinal data.

4. Findings

4.1 Research landscape and thematic clusters (RQ1)

Publication volume grew steadily from fewer than 50 documents in 2020 and peaked in 2024, before a lower count in 2025. The 2025 dip is plausibly explained by indexing delays and data-retrieval timing rather than waning interest, and may also reflect fragmentation into specialised topics such as carbon accounting, digital ethics and regenerative design

that fall outside the original keyword set. The literature moved from conceptual debate towards empirical, sector-specific studies in manufacturing, supply chains, smart cities and energy.

Table 7 shows the approximate annual output across the review period. The counts are read from the publication-trend figure in the underlying review and are therefore approximate; they sum to the 625 articles analysed.

Table 7. Documents published per year (approximate, 2020 to 2025)

Year	Documents	Share of sample	Trend
2020	about 23	about 4%	Early stage of interest
2021	about 41	about 7%	Growth after the pandemic shock
2022	about 71	about 11%	Steady growth
2023	about 111	about 18%	Rapid growth
2024	about 201	about 32%	Peak year
2025	about 178	about 28%	Lower count; likely indexing delay (partial year)
Total	625	100%	

Source: approximate values read from Figure 2 of Chieh and Mohezar (2025). The review's text describes 2024 as exceeding 220 publications, so exact counts should be confirmed against the Scopus export.

Cluster analysis identified five groups of studies, summarised in Table 8.

Table 8. Thematic clusters in the digital transformation and sustainable supply chain literature

#	Cluster	Core focus
1	Sustainable development	How digital transformation in supply chain operations supports the Sustainable Development Goals, especially SDG 8 (decent work and economic growth); digital platforms, entrepreneurship, gig work and inclusive participation (Nguyen et al., 2023).
2	Triple bottom line	Multi-dimensional effects on economic resilience (Putritamara et al., 2023), resource optimisation (Reza et al., 2025), environmental outcomes (Machado et al., 2024) and social outcomes such as workplace safety (Casciani et al., 2022; Liu & Chi, 2024).
3	Competencies	Human capital, technological literacy, organisational agility and sustainability-oriented leadership as success factors (Hariyani et al., 2025; Zhang et al., 2022).
4	Technology-enabled sustainability	Combined deployment of blockchain, big data analytics and IoT for real-time data, traceability and process optimisation (Mousa et al., 2025; Zhang et al., 2024; Jum'a et al., 2025).
5	Environmental uncertainty as driver	Pandemics, regulatory change, geopolitical turmoil and climate change as catalysts that push firms towards digital transformation (Ning & Yao, 2023).

Source: adapted from Chieh and Mohezar (2025).

4.2 Effects on supply chain efficiency and sustainable performance (RQ2)

Studies broadly agree that digital transformation improves sustainable supply chain performance, but the mechanisms and strength of the effect differ by dimension.

4.2.1 Economic performance and efficiency

The most consistent finding is a positive link between digital transformation and economic performance. Predictive and prescriptive analytics support data-driven decisions that improve production planning, logistics routing, inventory management and demand management, which raises productivity and service levels (Nazir et al., 2025; Liu & Chi, 2024). Cloud-based tools and IoT add transparency and seamless integration, leading to smoother process flow and lower cost.

Table 9 lists the main evidence on economic performance and efficiency.

Table 9. Evidence on economic performance and supply chain efficiency

Study	Focus	Reported effect
Nazir et al. (2025); Liu & Chi (2024)	Data-driven decision making through predictive and prescriptive analytics	Better production planning, logistics routing, inventory and demand management; higher productivity and service levels
Liu & Chi (2024)	Digital transformation and supply chain efficiency in China	Information sharing underpins coordination across supply chain partners
Türkeș (2025)	Romanian industry; role of process integration	Digitalisation alone insufficient; IoT and cloud tools support transparency, integration, lower cost and higher productivity when combined with integration
Mohaghegh et al. (2025)	Mediating supply chain capabilities	Effect mediated by supply chain agility and alignment; more robust and flexible processes
Zhou et al. (2023)	Turbulent environments in China	Large-scale data processing sustains agility; technology helps firms sense and respond to change

Source: synthesised from the studies cited in Section 4.2.1.

The effect is rarely direct. Türkeș (2025) finds that digitalisation alone may not be enough to improve performance without process integration and assimilation, and that it must be paired with cross-departmental communication and learning capability. Mohaghegh et al. (2025) report that the path from digital transformation to sustainable supply chain performance is mediated by supply chain agility and alignment, a pattern echoed in Chinese evidence (Zhou et al., 2023). In turbulent settings, firms must process large volumes of data to stay agile, and technology helps them sense and respond to change. These results rest mainly on resource-based, dynamic capabilities and resource orchestration theories.

Table 10. Mechanisms through which digital transformation affects supply chain performance

Mechanism	Role	Source
Process integration	Turns digital tools into performance; digitalisation alone is not sufficient	Türkeș (2025)
Cross-departmental communication and learning	Needed alongside digital transformation for outcomes to materialise	Türkeș (2025)
Supply chain agility	Mediates the link between digital transformation and sustainable performance	Mohaghegh et al. (2025); Meng et al. (2025)
Supply chain alignment	Mediates the link between digital transformation and sustainable performance	Mohaghegh et al. (2025)
Supply chain integration	Mediates the effect on organisational sustainable performance	Meng et al. (2025)
Dynamic capabilities and resource orchestration	Allow firms to reconfigure adopted technologies to attain positive outcomes	Theoretical grounding of the reviewed studies

Source: synthesised from the studies cited in Section 4.2.1.

4.2.2 Environmental performance

Digital tools such as IoT and big data analytics make resource consumption, carbon emissions and waste visible in real time along the supply chain (De la Calle et al., 2025; Sun et al., 2024; Meng et al., 2025). Digital transformation is also tied to circular economy practices, which require coordination between suppliers, customers, internal departments and other stakeholders. Without real-time data sharing, tracking and tracing become difficult. Meng et al. (2025) point to supply chain agility and integration as mediators of the effect on organisational sustainable performance.

Table 11 summarises the environmental evidence.

Table 11. Evidence on environmental performance

Study	Technology or practice	Reported effect
De la Calle et al. (2025); Sun et al. (2024); Meng et al. (2025)	IoT and big data analytics	Real-time monitoring of resource consumption, carbon emissions and waste along the supply chain
Meng et al. (2025)	Supply chain agility and integration as mediators	Effect on organisational sustainable performance runs through agility and integration
Karuppiah et al. (2024)	Circular economy in a digitally advanced supply chain	Real-time monitoring, predictive planning and integrated coordination replace fragmented data and reactive decisions
Synthesis of reviewed studies	Digital tools for circular economy coordination	Integration of suppliers, customers and internal departments; tracking and tracing are difficult without real-time data sharing

Source: synthesised from the studies cited in Section 4.2.2.

4.2.3 Social performance

Evidence on social outcomes is less developed. Emerging studies show that digital transformation can support monitoring of labour conditions, supplier compliance and ethical sourcing (Casciani et al., 2022), and that automating hazardous tasks can improve workplace safety, particularly in manufacturing (Ghobakhloo et al., 2025). At the same time, the literature flags digital divides, job displacement, concentration of power in digital platforms (Nosratabadi et al., 2023) and data privacy risks (Zheng & Walsham, 2021).

Table 12 summarises the social evidence, which is thinner than for the other two dimensions.

Table 12. Evidence on social performance

Study	Focus	Reported effect or concern
Casciani et al. (2022)	Fashion industry supply chains	Monitoring of labour conditions, supplier compliance and ethical sourcing
Ghobakhloo et al. (2025)	Human-centric, resilient manufacturing (Industry 5.0)	Automation of hazardous tasks improves workplace safety
Nosratabadi et al. (2023)	Social sustainability in EU-27 countries	Digital divides, job displacement and concentration of power in digital platforms; uneven benefits across regions
Zheng & Walsham (2021)	Digital inequality under COVID-19	Data privacy and inequality concerns

Source: synthesised from the studies cited in Section 4.2.3.

Table 13. Summary of reported effects of digital transformation across the triple bottom line

Dimension	Reported benefits	Reported risks and conditions
Economic	Data-driven planning; better routing, inventory and demand management; higher productivity and service levels; lower cost	Gains depend on process integration, agility and alignment; digitalisation alone is insufficient
Environmental	Real-time monitoring of emissions, resources and waste; support for circular economy; traceability	Requires inter-firm data sharing and integration; limited by weak data-protection and cybersecurity frameworks
Social	Monitoring of labour conditions and supplier compliance; automation of hazardous tasks; safer workplaces	Digital divides, job displacement, platform power, privacy and bias; evidence base still thin

Source: synthesised from the studies cited in Section 4.2.

4.3 Enabling technologies, capabilities and conditions (RQ3)

4.3.1 Technologies

Effective transformation relies on integrating advanced technologies such as IoT, blockchain, AI and big data analytics, which strengthen agility and transparency (Schöggl et al., 2023; Hamedani et al., 2025). The common characteristics of effective technologies are real-time data capture, supply chain integration and advanced analytics. By implication, stand-

alone systems that lack these characteristics, such as conventional ERP systems, play a limited role in enabling sustainable supply chain performance.

Table 14 maps each technology to its supply chain function, and Table 15 sets out the characteristics that make a technology effective.

Table 14. Enabling technologies and their reported contribution

Technology	Supply chain function	Reported contribution	Sources
Internet of Things	Real-time sensing	Tracks waste, emissions, equipment condition and logistics movement; improves visibility	Schöggl et al. (2023); Hamedani et al. (2025)
Blockchain	Traceability and transparency	Supports tracking and tracing across supply chain activities	Mousa et al. (2025); Zhang et al. (2024); Jum'a et al. (2025)
Artificial intelligence	Forecasting and anomaly detection	Forecasts energy demand and emissions, detects process anomalies, supports predictive maintenance	Uddin (2024); Ameh (2024)
Big data analytics	Planning and decision support	Predictive and prescriptive analytics for planning, routing, inventory and demand; monitoring of consumption	Nazir et al. (2025); Liu & Chi (2024); Mousa et al. (2025)
Cloud computing	Integration	Supports transparency and seamless integration	Türkeş (2025)

Source: synthesised from the studies cited in Sections 1 and 4.3.1.

Table 15. Characteristics of technologies that enable sustainable supply chain performance

Characteristic	Why it matters	Implication
Real-time data capture	Allows continuous monitoring and quick response	Visibility of waste, emissions and logistics movement
Supply chain integration	Allows data to flow across partners and tiers	Multi-tier visibility and shared data for emissions and traceability
Advanced analytics	Turns data into predictive decisions	Forecasting, predictive maintenance and planning
Absence of these characteristics	Stand-alone systems such as ERP lack real-time capture and integration	Limited role in enabling sustainable supply chain performance

Source: synthesised from Schöggl et al. (2023) and Hamedani et al. (2025).

4.3.2 Organisational capabilities

Four capability groups recur. First, digital leadership and culture: leaders who set a clear vision, support training and legitimise change reduce employee resistance and keep technology investment aligned with long-term value rather than

automation alone (Chen et al., 2024), and a digital-oriented culture promotes continuous learning (Alakaş, 2024). Second, dynamic capabilities allow firms to reconfigure processes so technologies fit operations. Third, collaboration capabilities, including inter-organisational trust, are needed because digital technologies must be spread across the supply chain for partners to share real-time data and trace products and emissions (Hamedani et al., 2025). Fourth, human capital and digital literacy underpin all of the above (Hariyani et al., 2025; Zhang et al., 2022).

Table 16 summarises the organisational capabilities identified in the evidence.

Table 16. Organisational capabilities that support digital transformation

Capability	Contribution	Sources
Digital leadership	Sets a clear vision, supports training and legitimises change; keeps investment aligned with long-term value	Chen et al. (2024)
Digital culture	Promotes continuous learning	Alakaş (2024)
Dynamic capabilities	Reconfigure processes so technologies fit operations	Theoretical grounding of the reviewed studies
Collaboration and inter-organisational trust	Enables shared real-time data and tracing across partners; avoids siloed systems	Hamedani et al. (2025)
Human capital and digital literacy	Skills to deploy and use digital technologies	Hariyani et al. (2025); Zhang et al. (2022)
Organisational agility	Readiness to change operations, strategies and skills	Hariyani et al. (2025); Zhang et al. (2022)

Source: synthesised from the studies cited in Section 4.3.2.

4.3.3 Environmental conditions

External conditions shape how far transformation pays off. Regulatory concerns are prominent because supply chain digitalisation involves cross-organisational data flows and multi-tier integration (Sharma et al., 2025). Sparse frameworks for data protection and cybersecurity can make firms cautious and incremental, which in turn hampers real-time data sharing needed for Scope 3 emissions reporting. In contrast, firms in highly regulated environments are more likely to adopt digital tools to demonstrate emissions monitoring and traceability. Environmental turbulence, including the pandemic, has accelerated transformation as firms seek adaptability and resilience (Datta & Nwankpa, 2021; Tsipoulanidis & Nanos, 2022).

Table 17 summarises the external conditions that shape outcomes.

Table 17. External conditions shaping the effectiveness of digital transformation

Condition	Effect on digital transformation	Sources
Sparse data-protection and cybersecurity rules	Cautious, incremental adoption; hampers real-time data sharing needed for Scope 3 reporting	Sharma et al. (2025)
Highly regulated environment	Greater adoption to demonstrate emissions monitoring and traceability	Synthesis of reviewed studies
Environmental turbulence (pandemic)	Accelerates transformation for adaptability and resilience	Datta & Nwankpa (2021); Tsipoulanidis & Nanos (2022)

Condition	Effect on digital transformation	Sources
Regulatory change, geopolitical turmoil, climate change	Catalysts that make digital transformation a strategic response to risk	Ning & Yao (2023)
Market demand and stakeholder pressure	Enabling conditions in the integrative framework	Framework in Section 6

Source: synthesised from the studies cited in Section 4.3.3.

4.4 Barriers and risks

Common barriers in supply chain settings include technological complexity, limited digital skills, cybersecurity exposure and high capital investment (Brunetti et al., 2020), and success is influenced by organisational culture and top management support (Favoretto et al., 2022). These barriers help explain uneven outcomes across firms and supply chains.

Table 18. Barriers to digital transformation in supply chains

Barrier	Description	Sources
Resistance to change	Employees resist new technologies, hindering a smooth transition	Abdallah et al. (2021)
Incompatible corporate culture	Culture does not support digital ways of working	Brunetti et al. (2020)
Limited technological capability	Firms lack the technical capability to implement and use technologies	Tian & Ou (2024)
Financial constraints	High capital investment requirements	Han & Zheng (2022); Brunetti et al. (2020)
Technological complexity	Complexity of integrating technologies across partners	Brunetti et al. (2020)
Lack of digital skills	Insufficient workforce skills	Brunetti et al. (2020)
Cybersecurity risk	Exposure from cross-organisational data flows	Brunetti et al. (2020)
Weak top management support	Success depends on culture and management commitment	Favoretto et al. (2022)
Privacy and bias	Algorithm-dependent technologies raise privacy and equity concerns	Nosratabadi et al. (2023); Zheng & Walsham (2021)

Source: synthesised from the studies cited in Sections 1, 2.3 and 4.4.

5. Survey Data Analysis (Synthetic Sample)

5.1 Data and analytical approach

This section analyses the 15-item questionnaire in Appendix A using a file of 120 records. Each record is labelled SYNTHETIC_SAMPLE_NOT_REAL_RESPONSE, so the dataset is synthetic. The section should therefore be read as a worked demonstration of the analysis that real data would receive. It does not report findings about real firms, and none of the figures below should be cited as empirical evidence. The file contains no missing values and no duplicate identifiers.

Responses to the twelve ordinal items were coded from 5 (option A, the most favourable response) to 1 (option E, the least favourable). Five construct scores were formed as the mean of their ordinal items: visibility and tracking (Q1, Q3), process automation and efficiency (Q4, Q6), data analytics, AI and decision-making (Q7 to Q9), agility, responsiveness and resilience (Q10 to Q12), and integration and collaboration (Q13, Q14). The three nominal items (Q2, Q5, Q15) were analysed as frequencies with chi-square goodness-of-fit tests against an equal split. Internal consistency was assessed with Cronbach's alpha, construct means were compared with the scale midpoint of 3 using Wilcoxon signed-rank tests, associations were measured with Spearman's rank correlation, and groups were compared with Kruskal-Wallis and Mann-Whitney tests. The significance level was .05, no correction for multiple testing was applied, and calculations were run in Python (pandas and SciPy).

5.2 Response distributions

Tables 19 to 21 show how respondents used the five response options on each ordinal item.

Table 19. Response frequencies, n (%): visibility, tracking and automation items

Item	A	B	C	D	E
Q1 Real-time visibility	27 (22.5%)	29 (24.2%)	30 (25.0%)	26 (21.7%)	8 (6.7%)
Q3 Tracking of goods movement	21 (17.5%)	35 (29.2%)	32 (26.7%)	23 (19.2%)	9 (7.5%)
Q4 Automation reducing manual work	18 (15.0%)	31 (25.8%)	37 (30.8%)	26 (21.7%)	8 (6.7%)
Q6 Automation impact on efficiency	24 (20.0%)	30 (25.0%)	37 (30.8%)	16 (13.3%)	13 (10.8%)

Note: A is the most favourable response and E the least favourable; option wording is given in Table A2. Source: author's analysis of the synthetic dataset (n = 120).

Table 20. Response frequencies, n (%): analytics and AI items

Item	A	B	C	D	E
Q7 Use of analytics and AI/ML	21 (17.5%)	27 (22.5%)	41 (34.2%)	18 (15.0%)	13 (10.8%)
Q8 Predictive forecasting effectiveness	28 (23.3%)	33 (27.5%)	30 (25.0%)	18 (15.0%)	11 (9.2%)
Q9 Data-driven risk management	26 (21.7%)	32 (26.7%)	36 (30.0%)	18 (15.0%)	8 (6.7%)

Note: A is the most favourable response and E the least favourable; option wording is given in Table A2. Source: author's analysis of the synthetic dataset (n = 120).

Table 21. Response frequencies, n (%): agility, resilience and integration items

Item	A	B	C	D	E
Q10 Speed of disruption response	23 (19.2%)	37 (30.8%)	31 (25.8%)	24 (20.0%)	5 (4.2%)
Q11 Adaptation to market demand	24 (20.0%)	29 (24.2%)	40 (33.3%)	22 (18.3%)	5 (4.2%)

Item	A	B	C	D	E
Q12 Maintaining operations in disruption	28 (23.3%)	33 (27.5%)	36 (30.0%)	15 (12.5%)	8 (6.7%)
Q13 Integrated platforms for sharing	25 (20.8%)	29 (24.2%)	38 (31.7%)	23 (19.2%)	5 (4.2%)
Q14 Digital communication and coordination	17 (14.2%)	39 (32.5%)	36 (30.0%)	16 (13.3%)	12 (10.0%)

Note: A is the most favourable response and E the least favourable; option wording is given in Table A2. Source: author's analysis of the synthetic dataset (n = 120).

Responses are spread across the scale rather than concentrated at either end. The share of favourable responses (A or B) ranges from 40.0% on Q7 to 50.8%, and the share of unfavourable responses (D or E) ranges from 19.2% to 28.3%. Item means (Table 23) lie between 3.21 and 3.48 on the five-point scale.

Figure 1 shows the full distribution of responses on the twelve ordinal items, ordered by the share of favourable responses. Favourable responses outnumber unfavourable ones on every item, but no item reaches 51% favourable. Predictive forecasting (Q8) and operations during disruption (Q12) rank highest at 50.8%, and the use of analytics and AI/ML (Q7) ranks lowest at 40.0%.

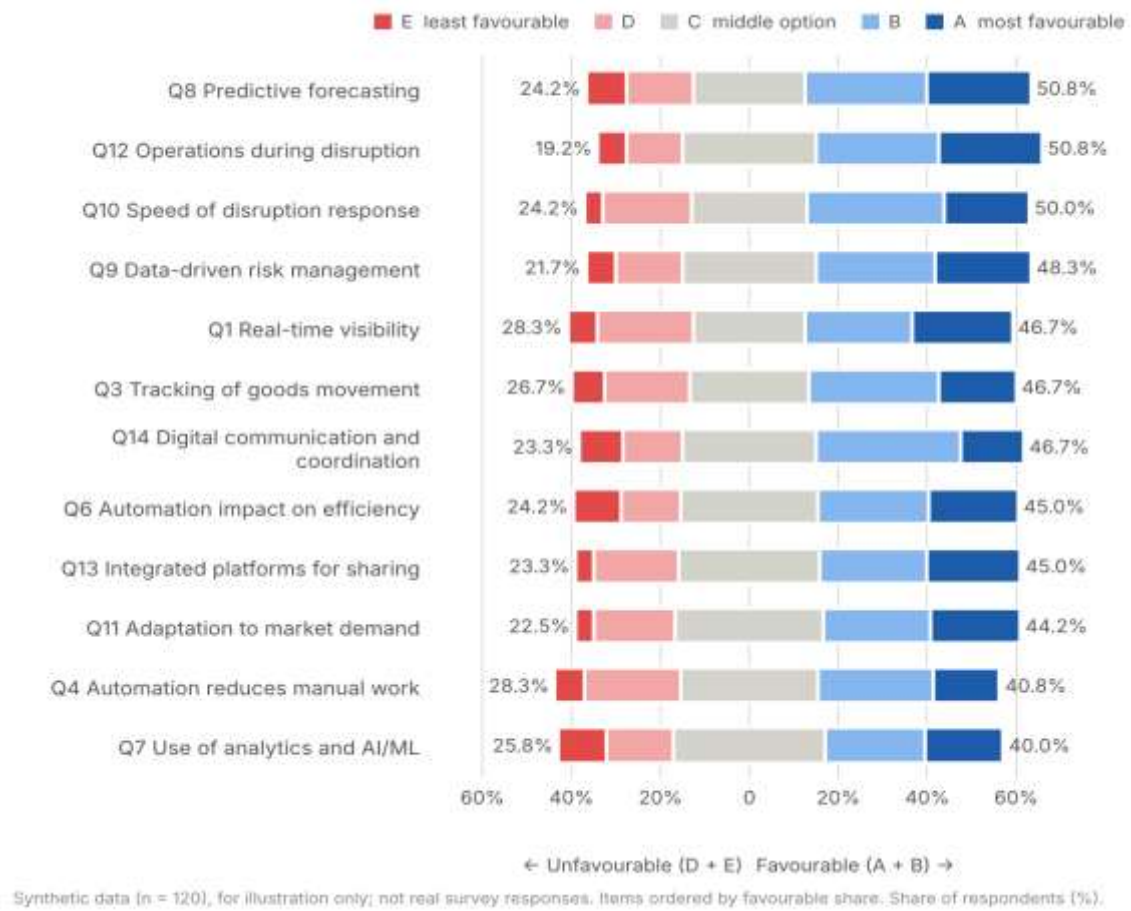


Figure 1. Distribution of responses on the twelve ordinal items

Note: segments show the share of respondents choosing each option from A (most favourable) to E (least favourable); labels at the bar ends give the unfavourable (D + E) and favourable (A + B) shares. Source: author's analysis of the synthetic dataset (n = 120).

Table 22. Technology and process choices (nominal items Q2, Q5 and Q15)

Item	Option	n	%	Chi-square test
Q2 Tracking technology	Internet of Things (IoT)	12	10.0	$\chi^2(4) = 11.25$, $p = .024$
	Enterprise Resource Planning (ERP)	33	27.5	
	GPS tracking systems	24	20.0	
	Cloud-based platforms	30	25.0	
	No digital tracking technology	21	17.5	
Q5 Process most helped by automation	Procurement and purchasing	21	17.5	$\chi^2(4) = 30.83$, $p < .001$
	Order processing	27	22.5	
	Inventory management	40	33.3	
	Logistics and transportation	29	24.2	
	None of the above	3	2.5	
Q15 Most important integration technology	Enterprise Resource Planning (ERP)	36	30.0	$\chi^2(4) = 21.58$, $p < .001$
	Cloud computing	29	24.2	
	Internet of Things (IoT)	28	23.3	
	AI and machine learning	21	17.5	
	Other digital technologies	6	5.0	

Note: the chi-square test compares the observed split with an equal split across the five options. Source: author's analysis of the synthetic dataset (n = 120).

Enterprise resource planning (ERP) was the most commonly reported tracking technology (27.5%), followed by cloud-based platforms (25.0%) and GPS tracking (20.0%). Only 10.0% reported using the Internet of Things (IoT) for real-time tracking, and 17.5% reported no digital tracking technology. Inventory management was named most often as the process that benefited most from automation (33.3%), ahead of logistics and transportation (24.2%) and order processing (22.5%). ERP was also most often named the most important integration technology (30.0%), with cloud computing (24.2%) and IoT (23.3%) close behind. All three distributions differ significantly from an equal split. On efficiency, 45.0% said automation improved efficiency significantly or moderately, while 24.2% reported no significant change or a decrease.

Figures 2 to 4 show the three nominal items as bar charts. ERP leads both for real-time tracking (27.5%) and for integration (30.0%), inventory management is the process that benefited most from automation (33.3%), and IoT is the least frequently chosen tracking option (10.0%).

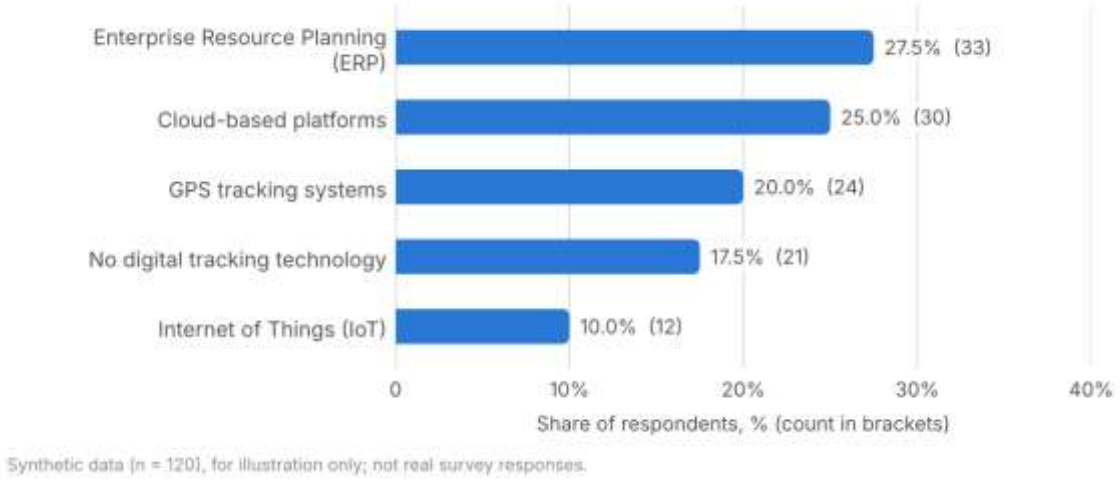


Figure 2. Technology mainly used to track inventory and logistics in real time (Q2)

Source: author's analysis of the synthetic dataset (n = 120).

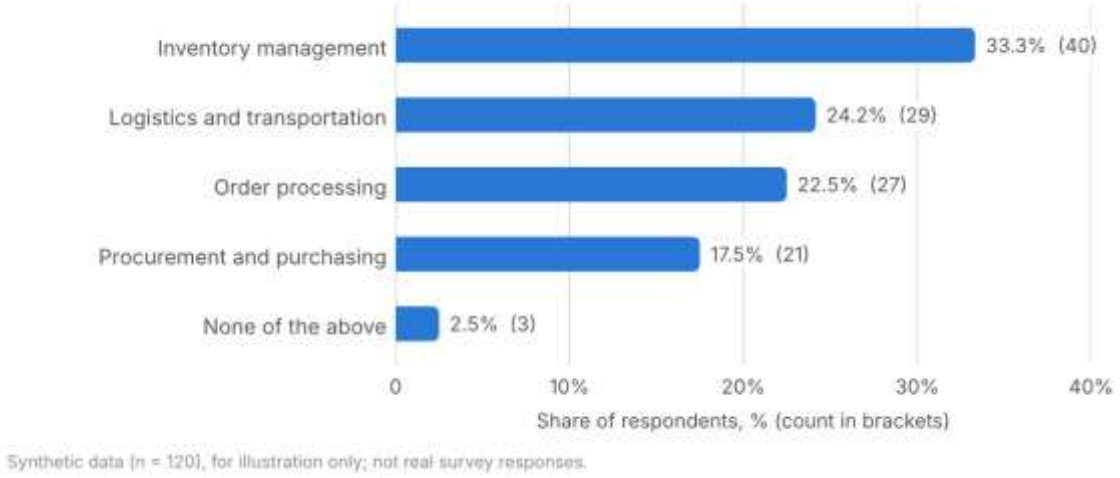


Figure 3. Supply chain process that benefited most from automation (Q5)

Source: author's analysis of the synthetic dataset (n = 120).

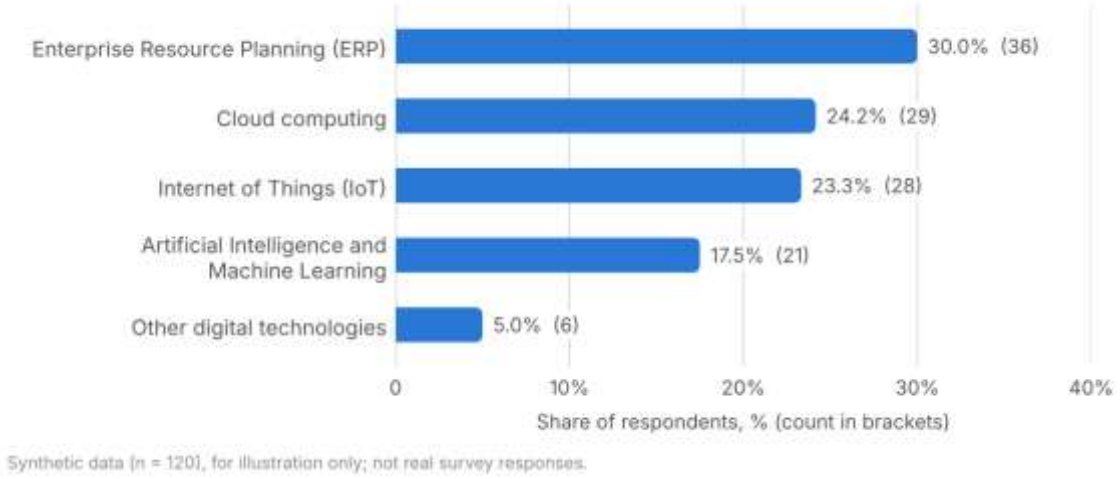


Figure 4. Technology most important for integration and collaboration (Q15)

Source: author's analysis of the synthetic dataset (n = 120).

Table 23. Descriptive statistics for the ordinal items (coded 1 to 5)

Item	M	SD	Median	Favourable (A+B), %	Unfavourable (D+E), %
Q1 Real-time visibility	3.34	1.23	3	46.7	28.3
Q3 Tracking of goods movement	3.30	1.19	3	46.7	26.7
Q4 Automation reducing manual work	3.21	1.14	3	40.8	28.3
Q6 Automation impact on efficiency	3.30	1.24	3	45.0	24.2
Q7 Use of analytics and AI/ML	3.21	1.22	3	40.0	25.8
Q8 Predictive forecasting effectiveness	3.41	1.25	4	50.8	24.2
Q9 Data-driven risk management	3.42	1.18	3	48.3	21.7
Q10 Speed of disruption response	3.41	1.13	4	50.0	24.2
Q11 Adaptation to market demand	3.38	1.12	3	44.2	22.5
Q12 Maintaining operations in disruption	3.48	1.17	4	50.8	19.2
Q13 Integrated platforms for sharing	3.38	1.14	3	45.0	23.3
Q14 Digital communication and coordination	3.27	1.17	3	46.7	23.3

Note: higher scores indicate more favourable responses. Source: author's analysis of the synthetic dataset (n = 120).

5.3 Construct scores and relationships

Table 24. Construct scores, reliability and comparison with the scale midpoint

Construct	Items	M	SD	α	Wilcoxon W	p (vs 3)
Visibility and tracking	Q1, Q3	3.32	0.90	0.21	1294.0	< .001
Process automation and efficiency	Q4, Q6	3.25	0.93	0.37	1455.0	.003
Data analytics, AI and decision-making	Q7, Q8, Q9	3.34	0.92	0.62	1653.0	< .001
Agility, responsiveness and resilience	Q10, Q11, Q12	3.42	0.77	0.38	1225.5	< .001
Integration and collaboration	Q13, Q14	3.33	0.89	0.34	1262.5	< .001

Note: construct score = mean of the listed items; α = Cronbach's alpha; the test compares each construct score with the scale midpoint of 3. Source: author's analysis of the synthetic dataset (n = 120).

Construct means range from 3.25 (process automation and efficiency) to 3.42 (agility, responsiveness and resilience), and all five lie significantly above the scale midpoint of 3 (Table 24). Cronbach's alpha ranges from 0.21 to 0.62 and is below the conventional benchmark of .70 for every construct, so the construct scores are treated as descriptive indices rather than validated scales. The short length of the scales (two or three items) contributes to the low values.

Figure 5 compares the five construct scores with the scale midpoint. All five bars extend beyond the midpoint, but the gap between the highest (agility, responsiveness and resilience, 3.42) and the lowest (process automation and efficiency, 3.25) is small.

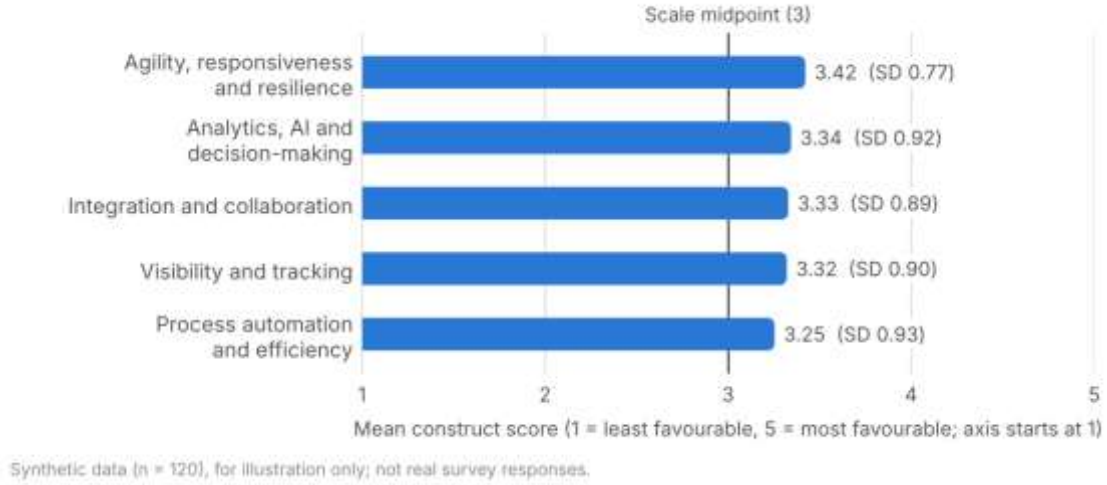


Figure 5. Mean construct scores compared with the scale midpoint

Note: bars start at 1, the lowest possible score; SD = standard deviation. Source: author's analysis of the synthetic dataset (n = 120).

Table 25. Spearman correlations between construct scores

Construct	1	2	3	4
2 Automation and efficiency	0.30 (< .001)			
3 Analytics, AI and decision-making	0.42 (< .001)	0.30 (< .001)		
4 Agility and resilience	0.40 (< .001)	0.32 (< .001)	0.54 (< .001)	
5 Integration and collaboration	0.36 (< .001)	0.21 (.021)	0.47 (< .001)	0.49 (< .001)

Note: cells show Spearman's ρ with the p-value in brackets. Source: author's analysis of the synthetic dataset (n = 120).

All ten correlations between constructs are positive and significant (Table 25). They range from ρ = 0.21 (automation and efficiency with integration and collaboration) to ρ = 0.54 (analytics and AI with agility and resilience). The two strongest links involve agility and resilience, which is related to data analytics and AI use (ρ = 0.54) and to integration and collaboration (ρ = 0.49). The association between analytics and agility remains after controlling for integration (partial ρ = 0.40, p < .001), and the association between integration and agility remains after controlling for analytics (partial ρ = 0.31, p < .001).

Figure 6 ranks the ten correlations between constructs. The three strongest all involve analytics and AI, agility or integration, and the weakest is between automation and integration (ρ = 0.21).

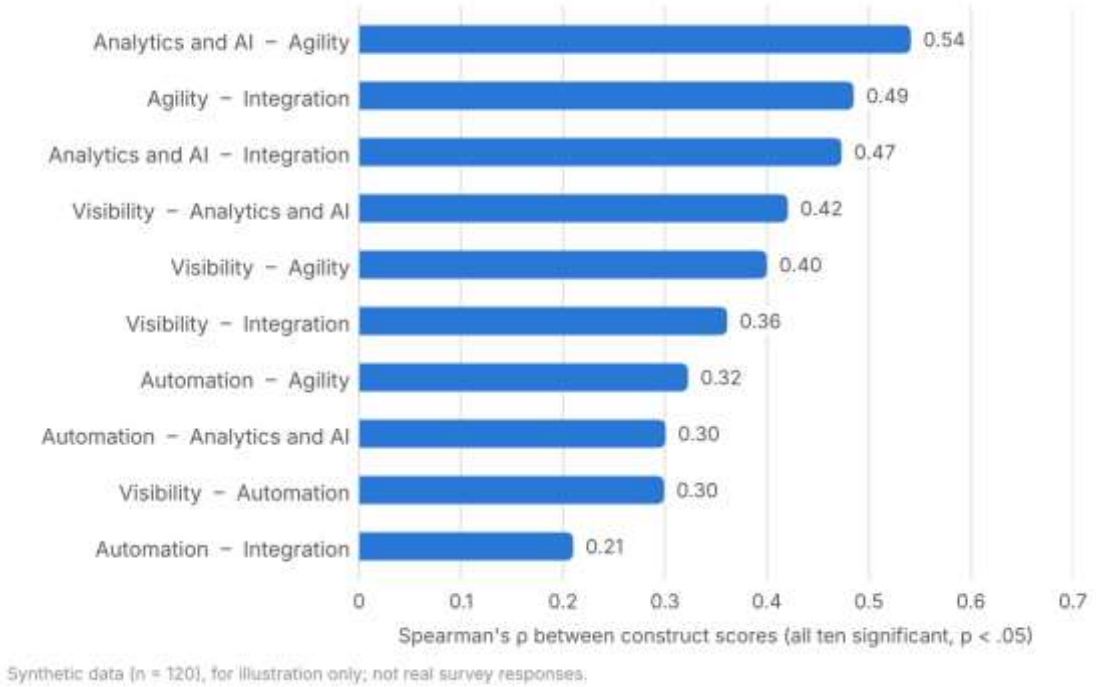


Figure 6. Spearman correlations between construct scores

Source: author's analysis of the synthetic dataset (n = 120).

Table 26. Selected item-level and partial correlations

Pair	ρ	p	Reading
Q1 and Q3: visibility and goods tracking	0.11	.232	very weak, not significant
Q4 and Q6: automation and efficiency	0.22	.018	weak
Q7 and Q8: analytics use and forecasting	0.23	.010	weak
Q8 and Q9: forecasting and risk management	0.38	< .001	weak
Q10 and Q12: disruption response and continuity	0.12	.207	very weak, not significant
Q13 and Q14: platform use and coordination	0.21	.023	weak
Q7 and Q6: analytics use and efficiency impact	0.23	.011	weak
Q13 and Q12: platform use and continuity	0.24	.009	weak
Partial: analytics and agility, controlling for integration	0.40	< .001	moderate
Partial: integration and agility, controlling for analytics	0.31	< .001	weak

Note: strength labels follow the usual bands (below .20 very weak, .20 to .39 weak, .40 to .59 moderate, .60 and above strong). Partial correlations are computed on ranks. Source: author's analysis of the synthetic dataset (n = 120).

At item level, the two visibility items (Q1 and Q3) are only weakly related (ρ = 0.11, p = .232), as are the first and last agility items (Q10 and Q12; ρ = 0.12, p = .207), which is consistent with the low reliability noted above. Automation is positively related to reported efficiency impact (Q4 and Q6; ρ = 0.22, p = .018), and analytics use is related both to

forecasting effectiveness (Q7 and Q8; ρ = 0.23) and to reported efficiency impact (Q7 and Q6; ρ = 0.23), although these associations are weak.

5.4 Differences by technology and process

Table 27. Visibility and efficiency scores by tracking technology (Q2)

Tracking technology	n	Visibility score, M	Efficiency impact (Q6), M
Internet of Things (IoT)	12	3.83	4.00
Enterprise Resource Planning (ERP)	33	3.36	3.27
GPS tracking systems	24	3.33	3.25
Cloud-based platforms	30	3.47	3.63
No digital tracking technology	21	2.74	2.52

Note: the IoT group is small (n = 12), so its means are imprecise. Source: author's analysis of the synthetic dataset (n = 120).

Table 28. Tests of group differences

Comparison	Test	Statistic	p	Effect size	Decision
Visibility score by tracking technology (Q2)	Kruskal-Wallis	H(4) = 12.91	.012	$\varepsilon^2 = 0.08$	Significant
Q1 real-time visibility by tracking technology	Kruskal-Wallis	H(4) = 14.78	.005	$\varepsilon^2 = 0.09$	Significant
Q3 goods tracking by tracking technology	Kruskal-Wallis	H(4) = 2.88	.578	$\varepsilon^2 = 0.00$	Not significant
Q6 efficiency impact by tracking technology	Kruskal-Wallis	H(4) = 14.81	.005	$\varepsilon^2 = 0.09$	Significant
Visibility score: IoT or cloud vs ERP users	Mann-Whitney	U = 779.0	.353	r = 0.12	Not significant
Q6 efficiency impact: IoT or cloud vs ERP users	Mann-Whitney	U = 841.5	.102	r = 0.21	Not significant
Q6 efficiency impact by process most helped (Q5)	Kruskal-Wallis	H(4) = 5.99	.200	$\varepsilon^2 = 0.02$	Not significant
Q4 manual work reduction by process most helped (Q5)	Kruskal-Wallis	H(4) = 3.86	.426	$\varepsilon^2 = 0.00$	Not significant

Note: ε^2 = epsilon-squared effect size for Kruskal-Wallis tests; r = rank-biserial correlation (positive when the first group scores higher). IoT or cloud users (n = 42) are compared with ERP users (n = 33). Source: author's analysis of the synthetic dataset (n = 120).

Firms that reported no digital tracking technology score lowest on both visibility (M = 2.74, against 3.33 to 3.83 for the other groups) and reported efficiency impact (M = 2.52, against 3.25 to 4.00) (Table 27). The differences across the five technology groups are significant for the visibility score (H(4) = 12.91, p = .012), for Q1 (p = .005) and for Q6 (H(4) = 14.81, p = .005), but not for Q3 (p = .578) (Table 28). Firms using IoT or cloud platforms score higher than ERP users

on visibility (3.57 against 3.36) and on efficiency impact (3.74 against 3.27), but neither difference is significant (p = .353 and p = .102). The process that benefited most from automation is not significantly related to reported efficiency impact (p = .200) or to reduced manual work (p = .426).

Figure 7 plots both scores for each tracking technology. Visibility and efficiency scores fall steadily from IoT users to firms with no digital tracking, and the no-technology group is lowest on both (2.74 and 2.52). The IoT group is small (n = 12), so its means should be read with caution.

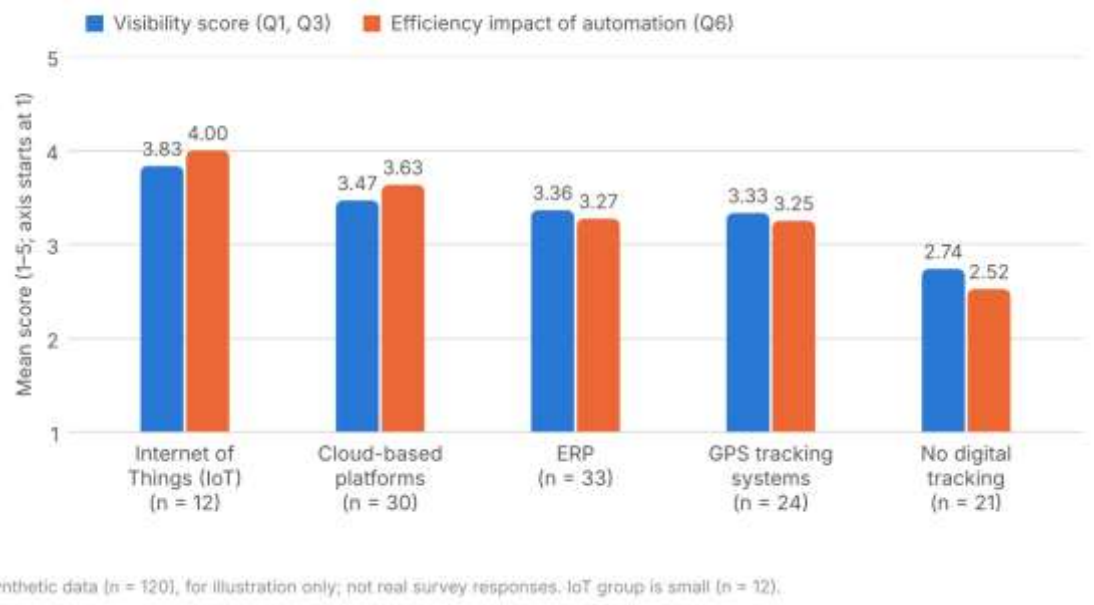


Figure 7. Visibility and efficiency scores by tracking technology (Q2)

Note: bars start at 1, the lowest possible score. Source: author's analysis of the synthetic dataset (n = 120).

5.5 Link to the propositions

Table 29. Survey results set against the four propositions

No.	What the survey can test	Result	Assessment
P1	Whether firms using real-time or integrated technologies (IoT, cloud) report better visibility and efficiency than firms using ERP or no digital tracking	Scores differ across technology groups (visibility H(4) = 12.91, p = .012; efficiency H(4) = 14.81, p = .005), with the no-technology group lowest. IoT or cloud users score higher than ERP users, but not significantly (visibility p = .353; efficiency p = .102).	Partly consistent; the key contrast is not significant
P2	Whether analytics use and integration are associated with agility and resilience	Analytics and agility ρ = 0.54 and integration and agility ρ = 0.49 (both p < .001); partial associations remain (0.40 and 0.31, both p < .001).	Consistent with mediation, which is not formally tested
P3	Leadership, culture and collaboration capabilities are not measured; Q13 and Q14 capture only platform use and coordination	No test possible	Not testable with this instrument

No.	What the survey can test	Result	Assessment
P4	Regulatory clarity and environmental turbulence are not measured	No test possible	Not testable with this instrument

Note: results are from a synthetic dataset and show the form the assessment would take with real data. Source: author's analysis of the synthetic dataset (n = 120).

Taken together, the synthetic data show a pattern in which firms with more analytics use and better integration also report greater agility and resilience, and in which firms without digital tracking report weaker visibility and efficiency. These results are illustrative. The sample is synthetic, the construct scores have low internal consistency, the design is cross-sectional so no causal direction can be inferred, more than thirty tests were run without correction for multiple comparisons, and the instrument contains no items on leadership, culture or regulation, so two of the four propositions cannot be tested with it.

6. Discussion

Across the three research questions, the evidence points to digital transformation as a socio-technical process. Efficiency and sustainability outcomes do not follow from adopting technology; they emerge from the interaction of technological characteristics, organisational capabilities and environmental context. The literature has also shifted from technology-centric and economic perspectives towards multi-dimensional views of performance, and from reactive environmental management towards proactive, data-enabled sustainability strategies.

Table 30 sets out the integrative framework that follows from this synthesis.

Table 30. Integrative framework of digital transformation and supply chain performance

Component	Elements	Role in the framework
Enabling conditions	Advanced technologies (big data, AI, IoT, blockchain); organisational capabilities (digital skills, leadership, culture, agility); environmental conditions (regulation, market demand, stakeholder pressure)	Determine how far digital transformation can be translated into outcomes
Digital transformation	Data-driven integration; process reconfiguration; cross-organisational coordination	Core mechanism that converts technology into visibility, coordination and responsiveness
Performance outcomes	Supply chain efficiency and economic performance; environmental performance; social performance	Triple bottom line outcomes
Contingencies and risks	Governance, data security and ethics; social and environmental trade-offs	Moderate or constrain outcomes; make effects contingent rather than deterministic

Source: adapted from the conceptual framework in Chieh and Mohezar (2025).

The framework suggests four propositions for future testing, set out in Table 31.

Table 31. Propositions for future research

No.	Proposition	Basis in the evidence
P1	Digital transformation improves supply chain efficiency more strongly when it enables real-time data capture, integration and analytics than when it consists of stand-alone or legacy systems.	Section 4.3.1 (Schöggl et al., 2023; Hamedani et al., 2025)
P2	The effect of digital transformation on supply chain efficiency is mediated by supply chain agility, integration and alignment.	Section 4.2.1 (Mohaghegh et al., 2025; Meng et al., 2025; Türkeş, 2025)
P3	Digital leadership, digital culture and collaboration capabilities strengthen the link between technology adoption and efficiency outcomes.	Section 4.3.2 (Chen et al., 2024; Alakaş, 2024; Hamedani et al., 2025)
P4	Regulatory clarity on data protection and cybersecurity, together with environmental turbulence, increases the extent to which firms translate digital transformation into measurable efficiency and sustainability gains.	Section 4.3.3 (Sharma et al., 2025; Datta & Nwankpa, 2021; Tsipoulanidis & Nanos, 2022)

Source: author synthesis.

The illustrative analysis in Section 5 points in the same direction as the literature, because agility and resilience scores are most strongly associated with analytics use and integration, and firms without digital tracking report the weakest visibility and efficiency. Because that analysis uses a synthetic dataset, it demonstrates how the propositions could be tested and does not confirm them.

The evidence also cautions against techno-centrism. Digital tools are only as effective as the systems and people that deploy them, and strategic alignment matters more than adoption alone. The positive social effects should be read with care, because workforce displacement, digital divides and platform concentration can offset them.

7. Implications

7.1 Theoretical implications

The synthesis supports capability-based and contextual explanations of digital transformation outcomes. It extends resource-based and dynamic capabilities arguments to supply chains by showing that integration, agility and inter-organisational trust operate as mediating or enabling mechanisms. It also argues for treating efficiency, environmental and social performance jointly rather than as isolated outcomes.

7.2 Managerial implications

- Prioritise technologies that capture real-time data, integrate across partners and support advanced analytics over stand-alone or legacy systems.
- Invest in employee upskilling, digital leadership and a learning culture alongside technology spending.
- Pursue a balanced agenda in which efficiency gains are matched by environmental and social responsibility, including ethical data practices and inclusive digital access for supply chain partners.
- Build partnerships with technology providers, logistics partners and sustainability experts to overcome resource constraints and speed capability development.
- Position digital solutions around environmental efficiency and social value to attract sustainability-oriented customers, partners and investors.

7.3 Policy implications

Clearer rules on data protection, cybersecurity and cross-organisational data sharing would reduce the caution that currently slows real-time information exchange. Support for digital skills and infrastructure, especially for smaller firms and less-connected regions, can limit the digital divides that the literature identifies.

8. Limitations and Future Research

Several limitations apply. The evidence base draws on a single database (Scopus), one subject area and English-language journal articles, so relevant work elsewhere may be missing. The 2025 data are incomplete. The cluster structure reflects the review's own grouping choices. This paper synthesises published findings rather than re-running the search or re-extracting data, so it should be read as an interpretive consolidation. The survey analysis in Section 5 rests on a synthetic dataset of 120 records, so it cannot support empirical claims. It also measures only some of the constructs in the framework, uses short scales with low internal consistency, is cross-sectional, and holds no information on respondent or firm characteristics, so group comparisons by size, sector or region were not possible.

The first step is to administer the questionnaire to real supply chain practitioners and repeat the analysis in Section 5, adding items on leadership, culture and regulation so that all four propositions can be tested. Future studies could then test the propositions with longitudinal designs that capture how contingency factors operate over time; examine the under-researched social dimension, including labour effects and equity; compare sectors and national regulatory settings; and use multiple databases and mixed methods to widen coverage. Quantitative evidence that separates efficiency gains from broader sustainability gains would also help managers judge trade-offs.

9. Conclusion

Digital transformation can raise supply chain efficiency, and it can do so while advancing environmental and, to a lesser and less certain extent, social goals. The evidence from 2020 to 2025 shows, however, that these results are conditional. They depend on integrated, real-time technologies, on leadership, culture, agility and collaboration inside and across firms, and on regulatory and market conditions. Firms that treat digital transformation as a technology purchase are unlikely to realise the benefits; those that treat it as an organisational and supply chain-wide change effort are better placed to do so. Research that tests these conditions directly, especially for social outcomes, is the next step for the field. The illustrative survey analysis in this paper shows how that testing can be carried out once real response data are available.

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Appendix A. Survey Instrument

Table A1 maps the questionnaire items to the constructs and to the research questions. Table A2 reproduces the 15 items with their response options.

Table A1. Questionnaire constructs and their link to the literature

Construct	Items	Link to the review findings	Response type
Real-time visibility and tracking	Q1 to Q3	Real-time data capture and tracking technologies (Section 4.3.1; RQ3)	Q1, Q3 ordinal; Q2 nominal
Process automation and efficiency	Q4 to Q6	Economic performance and operational efficiency (Section 4.2.1; RQ2)	Q4, Q6 ordinal; Q5 nominal
Data analytics, AI and decision-making	Q7 to Q9	Predictive and prescriptive analytics for planning and risk management (Sections 4.2.1 and 4.3.1)	Ordinal
Agility, responsiveness and resilience	Q10 to Q12	Supply chain agility as a mediator; turbulence as a driver (Sections 4.2.1 and 4.3.3)	Ordinal
Integration and collaboration	Q13 to Q15	Supply chain integration and inter-organisational collaboration (Sections 4.2.1 and 4.3.2)	Q13, Q14 ordinal; Q15 nominal

Source: author design, based on the synthesis in Section 4.

Table A2. Survey questionnaire

No.	Question	Response options
1	To what extent does your organization have real-time visibility across the entire supply chain?	A) Very high B) High C) Moderate D) Low E) Very low
2	Which technology is primarily used by your organization to track inventory and logistics in real time?	A) Internet of Things (IoT) B) Enterprise Resource Planning (ERP) C) GPS tracking systems D) Cloud-based platforms E) No digital tracking technology
3	How effectively does your organization track the movement of goods from suppliers to customers?	A) Extremely effectively B) Very effectively C) Moderately effectively D) Slightly effectively E) Not effectively at all

No.	Question	Response options
4	To what extent has automation reduced manual intervention in your supply chain operations?	A) To a very great extent B) To a great extent C) To a moderate extent D) To a small extent E) Not at all
5	Which supply chain process has benefited the most from automation in your organization?	A) Procurement and purchasing B) Order processing C) Inventory management D) Logistics and transportation E) None of the above
6	How has process automation affected the operational efficiency of your organization?	A) Improved significantly B) Improved moderately C) Improved slightly D) No significant change E) Efficiency has decreased
7	To what extent does your organization use data analytics and AI/ML for supply chain decision-making?	A) To a very great extent B) To a great extent C) To a moderate extent D) To a small extent E) Not at all
8	How effective is predictive forecasting in improving demand planning and inventory management in your organization?	A) Extremely effective B) Very effective C) Moderately effective D) Slightly effective E) Not effective at all
9	To what extent does data-driven decision-making help your organization identify and manage supply chain risks?	A) To a very great extent B) To a great extent C) To a moderate extent D) To a small extent E) Not at all
10	How quickly can your organization respond to unexpected supply chain disruptions?	A) Very quickly B) Quickly C) Moderately quickly D) Slowly E) Very slowly
11	To what extent has digital transformation improved your organization's ability to adapt to changes in market demand?	A) To a very great extent B) To a great extent C) To a moderate extent D) To a small extent E) Not at all

No.	Question	Response options
12	How effective is your organization's supply chain in maintaining operations during unexpected disruptions?	A) Extremely effective B) Very effective C) Moderately effective D) Slightly effective E) Not effective at all
13	To what extent does your organization use integrated digital platforms to share information with suppliers and business partners?	A) To a very great extent B) To a great extent C) To a moderate extent D) To a small extent E) Not at all
14	How effectively do digital technologies improve communication and coordination among supply chain stakeholders?	A) Extremely effectively B) Very effectively C) Moderately effectively D) Slightly effectively E) Not effectively at all
15	Which technology is most important for improving integration and collaboration across your supply chain?	A) Enterprise Resource Planning (ERP) B) Cloud computing C) Internet of Things (IoT) D) Artificial Intelligence (AI) and Machine Learning (ML) E) Other digital technologies

Source: author-designed questionnaire.