

Digital Transformation of Transport Logistics: from 1.0 to 4.0

Nistor ANDREI*

Doctoral School of Entrepreneurship, Business Engineering & Management, National Science and Technology University Politehnica of Bucharest

ORCID ID: <https://orcid.org/0009-0009-6075-5679>

*Corresponding author, nandrei.upb@gmail.com

Alexandru-Adrian BLĂGĂU

Doctoral School of Entrepreneurship, Business Engineering & Management, National Science and Technology University Politehnica of Bucharest

ORCID ID: <https://orcid.org/0009-0001-4890-571X>

alex.blagau@gmail.com

Abstract. The transport and logistics sector is undergoing profound changes driven by digital transformation, evolving from early computerized planning (1.0) to highly integrated, AI-powered systems (4.0). Existing literature outlines successive waves of digitalization: initial route optimization tools, sensor-based IoT and telematics for real-time monitoring, advanced geospatial tracking platforms for supply chain visibility, and, most recently, artificial intelligence and machine learning for predictive and adaptive decision-making. However, despite substantial research on individual technologies, fewer studies systematically map these phases as an integrated transformation continuum. This paper addresses that gap by reviewing the technological evolution of transport logistics through the 1.0–4.0 framework and analyzing how these stages build on one another toward autonomous systems. Methodologically, the paper employs a structured literature review combined with conceptual modeling to answer two research questions: (1) How can the historical evolution of transport logistics digitalization be categorized into coherent stages? (2) What are the implications of this staged transformation for operational efficiency, visibility, and strategic decision-making? The main results outline a four-stage model of digital transformation, demonstrating the cumulative integration of IoT, geospatial data, and AI in creating intelligent, interconnected systems. The paper highlights implications for fleet management, predictive maintenance, demand forecasting, and dynamic routing, contributing to improved responsiveness and resilience in supply chains. This work contributes to the field by offering a clear, stage-based conceptual framework to understand digital transformation in transport logistics, supporting both academic research and practical planning for technology adoption in the sector.

Keywords: transport logistics, digital transformation, Industry 4.0, Internet of Things, artificial intelligence, supply chain visibility.

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Introduction

Transport and logistics represent critical sectors of the global economy, responsible for moving goods efficiently and reliably across complex supply chains. In recent decades, these sectors have experienced profound change driven by successive waves of digitalization. This process, often framed as the shift from Industry 3.0 to Industry 4.0, is marked by the integration of advanced technologies such as the Internet of Things (IoT), geospatial tracking, and artificial intelligence (AI).

Digital transformation in transport logistics is not a single, uniform leap but rather a multi-stage evolution. It began with early computer-based route planning (Digitalization 1.0), advanced through real-time monitoring via IoT and telematics (2.0), expanded into geospatial visibility and data-sharing platforms (3.0), and now moves toward AI-driven adaptive and autonomous systems (4.0). Each stage builds upon the capabilities of the previous one, leading to increasingly integrated, responsive, and resilient logistics systems.

The importance of understanding this transformation lies in its significant impact on operational efficiency, supply chain visibility, customer responsiveness, and competitive advantage. While individual technological

innovations have been studied extensively in the literature, there is a need for an integrated framework that systematically describes and analyzes these phases as part of a continuum of digital transformation.

There are two research questions guiding this paper. First question (RQ1) is *How can the historical evolution of transport logistics digitalization be categorized into coherent stages?* The second research question (RQ2) is trying to find *What are the operational and strategic implications of this staged transformation for logistics companies?*

The main hypotheses of this paper are that (H1) *the evolution of transport logistics digitalization can be meaningfully structured into four stages (1.0 to 4.0), each characterized by specific enabling technologies and operational capabilities*, and that (H2) *the cumulative integration of these technologies leads to measurable improvements in efficiency, visibility, and decision-making agility in logistics systems*.

To address these questions, this paper adopts a structured literature review and conceptual modeling approach to develop a clear stage-based framework for understanding digital transformation in transport logistics, offering both theoretical insight and practical guidance for technology adoption.

Literature review

The evolution of transport logistics can be delineated into successive “Digitalization” stages from 1.0 through 4.0, each characterized by key technological adoptions that enhanced efficiency, visibility, and operational performance. Recent literature reviews in maritime and supply chain domains explicitly describe these successive IT-based generations: from basic computerization (Digitalization 1.0) to IoT and sensing (2.0), geospatial tracking (3.0), and AI-driven autonomy (4.0). This section synthesizes academic and industry insights on each stage’s defining technologies and their contributions to logistics operations.

Digitalization 1.0: early computerization and route planning

The first stage of logistics digitalization began with the introduction of computers and algorithmic tools to replace manual planning. In this era, simple software applications and optimization algorithms were applied to problems like vehicle routing and scheduling, yielding significant efficiency gains. For example, the adoption of computer-based route planning allowed companies to calculate more efficient delivery sequences than human planners, reducing total mileage and fuel consumption.

Scarlat, Ioanid and Andrei [1] identify this shift (computer-based optimization of transport routes) as the foundational digital breakthrough in maritime and transport logistics. By leveraging early decision-support systems, firms could better utilize assets, cut transit times, and improve service reliability. This stage established a mindset of using data and software to drive logistics performance, laying the groundwork for further innovation.

In essence, Digitalization 1.0 injected basic computational intelligence into logistics operations, optimizing processes that were previously labor-intensive. This transition boosted operational efficiency and demonstrated the value of innovation in logistics management [2].

Digitalization 2.0: telematics and enterprise connectivity

In the second stage, roughly coinciding with the 1990s–2000s, logistics systems became more connected and visible through telematics, sensors, and enterprise integration. The proliferation of intelligent sensors, onboard telematics, and early IoT devices in this era enabled real-time monitoring of vehicles and shipments [3]. Trucks were outfitted with GPS units and communication modules, allowing fleet managers to track locations and vehicle conditions in transit. This development markedly improved logistics visibility and responsiveness. For instance, by the 2000s many trucking fleets could monitor their trucks’ positions and driving behavior in real time, facilitating dynamic rerouting or maintenance planning to prevent breakdowns [4, 5].

Kartsan [6] notes that advancements like GPS and telematics made transportation “more accurate in spending and thus more cost-effective” by automating formerly manual tasks and providing timely data. At the same time, enterprise systems such as electronic data interchange (EDI) and early transportation management systems linked shippers, carriers, and warehouses, so that shipment information could be exchanged instantly across the supply chain [7]. The literature underscores that this connectivity brought efficiency and reliability benefits: shipments could be scheduled and tracked more tightly, reducing delays and uncertainties.

In summary, Digitalization 2.0 introduced networked logistics – vehicles, infrastructure, and organizations began sharing data. The use of telematics and connected IT systems streamlined coordination (e.g. automatic status updates, digital documentation) and improved decision-making with real-world data. As a result, logistics operations saw better asset utilization and service levels. These developments foreshadowed the more sophisticated sensor and communication networks of Logistics 4.0, establishing an early template for data-driven logistics management.

Digitalization 3.0: IoT, Geospatial Tracking and Real-Time Visibility

The third stage, often associated with the 2010s, saw an explosion of IoT (Internet of Things) devices, geospatial technologies, and big-data integration in logistics. In this phase, the basic telematics of 2.0 evolved into pervasive sensing and monitoring of all logistics assets and position monitoring by using geospatial technologies and databases became standard [8–10]. Practically, this meant that every shipment, container, and vehicle could be equipped with GPS trackers or RFID tags, feeding location and status data into cloud platforms. The result was end-to-end, real-time visibility of supply chain movements [10].

Academic studies emphasize how this tracking system transformed logistics operations. For example, Andrei et al. [11] highlight the role of GIS-based sensors and route optimization in modern logistics, showing that integrating geospatial data allows dynamic rerouting and precise delivery planning that cut fuel usage and emissions. With IoT sensors capturing location, temperature, vibration, etc., companies could ensure product quality (crucial in cold chains) and trigger alerts for any deviation. Leuck and Morrison [12] note that IoT-enabled real-time visibility permits swift responses to disruptions and supports just-in-time management by continuously tracking shipments and asset conditions.

In warehousing, IoT and advanced management systems enabled live inventory updates and automated reordering. Overall, Digitalization 3.0 greatly improved logistics transparency and agility: managers could “see” the supply chain as it happened and make data-informed adjustments [13, 14]. This stage also brought higher-level integration of systems as Transportation Management Systems, Warehouse Management Systems, and supply chain platforms began to interconnect, often via cloud-based services, to consolidate the torrent of IoT data [15].

The literature credits these capabilities with significant operational improvements: delays and bottlenecks became easier to anticipate and mitigate, customer service benefitted from accurate tracking information, and efficiency improved through refined routing and scheduling. Crucially, the third stage set the stage for predictive and autonomous logistics by providing the rich data streams on which AI and analytics could act.

In summary, Digitalization 3.0 is defined by sensor-driven visibility and control, yielding unprecedented situational awareness in transport logistics (often referred to as the rise of “smart logistics”). The ability to monitor the network in real time markedly enhanced both day-to-day efficiency and the capacity to manage exceptions, thus elevating the performance and robustness of logistics operations.

Digitalization 4.0: AI, Automation and Autonomous Logistics

The current frontier and future trend, Digitalization 4.0, corresponds to the Industry 4.0 paradigm applied to logistics (Logistics 4.0), an era of artificial intelligence, machine learning, automation, and autonomous systems deeply integrating into supply chains [16]. This stage builds on the connectivity and data availability of prior stages to enable intelligent decision-making and self-optimizing processes. A hallmark of Logistics 4.0 is the use of AI-driven analytics and predictive algorithms to enhance efficiency and responsiveness. For instance, machine learning models now analyze the big data from IoT systems to forecast demand and optimize routes in real time, considering traffic, weather, and delivery constraints. Leuck and Morrison [12] underscore that AI-powered demand forecasting and routing are revolutionizing logistics by improving accuracy and reducing costs – better predictions prevent stockouts and AI route optimization cuts fuel and transit time. One concrete example is the integration of dynamic routing algorithms that re-optimize delivery routes on the fly as new orders or disruptions occur. A recent study [17] introduced a dynamic routing approach that uses predicted orders (via AI) to schedule last-mile deliveries in time-slot programs, significantly improving delivery efficiency and customer satisfaction.

Another pillar of stage 4 is automation and robotics. Advanced robotics have been deployed in warehouses and across transport modes, moving the industry toward cyber-physical systems. Automated guided vehicles (AGVs) and autonomous mobile robots now handle material movement and order picking in modern distribution centers, operating 24/7 with high accuracy. One study [18] examines a novel multi-deep robotic storage system where climbing robots retrieve goods from high-density racks without the need for aisles, drastically increasing storage density and throughput while lowering energy consumption. Such robotic automation raises productivity and improves safety and labor flexibility (human workers are augmented or relocated to higher-level tasks). In transportation, we see the advent of autonomous vehicles and drones. Trials of self-driving trucks and delivery drones indicate potential for faster, more flexible deliveries with lower labor costs. Andrei, Scarlat and Ioanid [11] demonstrate in a case study that autonomous transport (from maritime vessels to last-mile robots) can “significantly enhance the efficiency, flexibility and sustainability” of logistics networks. These autonomous systems leverage AI for navigation and coordination, and when combined with concepts like synchromodal logistics (dynamically choosing transport modes) [19] they can optimize routes and schedules far beyond static planning.

Additionally, blockchain technology has emerged as part of the Logistics 4.0 toolkit to improve data security, transparency, and trust in complex supply chains. By providing an immutable ledger of transactions and asset statuses, blockchain can enable end-to-end visibility of products and documents, reducing fraud and easing compliance. For example, in cold chains or pharmaceutical logistics, blockchain can certify provenance and condition data, assuring all stakeholders of the integrity of deliveries. Leuck and Morrison [12] note that blockchain is increasingly used to “provide transparency, traceability, and security,” building trust between shippers, carriers, and customers. Likewise, another article [20] proposed a blockchain-supported cloud logistics model to improve service resilience in warehousing, indicating tangible benefits in reliability.

Furthermore, stage 4 integrates a strong emphasis on data-driven decision support and digital twins. Companies are now creating digital twin models of their logistics networks, virtual replicas that simulate operations (e.g., port terminals or distribution routes) in order to test scenarios and optimize without disrupting the real system. This approach allows for proactive planning and risk management. As one study [12] observes, digital twin technology helps firms identify bottlenecks and evaluate “what-if” scenarios, leading to more resilient supply chain designs. The concept of resilience is indeed an important advancement in this stage. With AI and real-time data, logistics systems can anticipate disruptions (such as forecasted storms or supply shortages) and adjust in advance. Recent comprehensive reviews (e.g., [21]) highlight that Logistics 4.0, by combining Industry 4.0 technologies, creates more agile and resilient logistics capable of withstanding volatility. A digitally transformed supply chain can reroute shipments, find alternate suppliers, or adjust production schedules autonomously in response to sensed conditions, thereby maintaining service levels where earlier generations might have failed.

Digitalization 4.0 also aligns logistics with sustainability goals. The same technologies that improve efficiency can also reduce environmental impact (a core aspect of “green logistics 4.0.”). For example, AI route optimization lowers costs and also directly cuts fuel consumption and emissions by minimizing unnecessary mileage. IoT sensors help monitor energy usage and emissions in warehouses and transport, enabling continuous improvement in carbon footprint. Scholars have started to explicitly connect digital transformation with environmental performance: empirical studies in China find that the digital transformation of logistics firms significantly boosts green innovation and efficiency in supply chains [22–24]. Similarly, one study [14] reviews effective smart technologies for reducing pollution in warehouse operations, reflecting a broader trend that the logistics 4.0 paradigm inherently supports sustainability (through optimized resource use, reduced waste, and better coordination). In summary, the 4.0 stage represents the integration of AI, automation, and connectivity to create intelligent, self-regulating logistics systems. These systems deliver improvements across multiple dimensions: operational efficiency (cost and speed), visibility (end-to-end transparency), reliability and resilience (robustness to shocks), and sustainability (lower environmental impact).

The literature consistently portrays the digital transformation of transport logistics as a progressive integration of technologies through these stages, rather than isolated leaps. Each stage built upon the last: the early computerization (1.0) enabled basic optimizations; connectivity and telematics (2.0) provided data streams; IoT and geospatial tech (3.0) vastly expanded real-time control; and finally AI and automation (4.0) leverage those data and networks to fundamentally reinvent logistics operations. Table 1 summarizes the stages, key technologies, and benefits. What is clear from academic analyses and industry reports is that the culmination of Digitalization 1.0 – 4.0 is a highly efficient, visible, and agile logistics ecosystem. Companies that embraced these technologies have reported streamlined processes, improved service levels, and new capabilities like end-to-end traceability and predictive management.

Table 1: The digitalization stages in logistics.

Digitalization 1.0:	
Simple route planning, static optimization, partial digitalization.	
Digitalization 2.0:	
Real time IoT monitoring, remote sensors, predictive maintenance.	
Digitalization 3.0:	
Precise geospatial data, digital data sharing platforms, logistic chain visibility.	
Digitalization 4.0:	

Artificial Intelligence, machine learning, adaptive and autonomous decisions, total data integration.

Source: Authors' own research.

The concept of Logistics 4.0 extends the Industry 4.0 vision into supply chains, emphasizing interconnection, data-driven intelligence, and automation. As research continues to explore this frontier (with studies anticipating fully driverless transport, AI-orchestrated supply networks, and advanced analytics for strategic decision-making) it is evident that digital transformation is not a one-time event but an ongoing journey. Transport logistics now operates on a new level of integration and smart capability unimaginable in the pre-digital era, demonstrating how each wave of technology has incrementally contributed to a more efficient, transparent, and responsive logistics industry.

Methodology

This research adopts a structured literature review and conceptual modeling approach to analyze the evolution of digital transformation in transport logistics, with the goal of developing a clear, stage-based framework that describes the shift from Digitalization 1.0 to 4.0. The study is designed to answer two primary research questions: how the historical evolution of transport logistics digitalization can be categorized into coherent stages, and what operational and strategic implications this staged transformation holds for logistics firms. The main hypotheses propose that this evolution can be meaningfully structured into four stages, each characterized by specific enabling technologies and operational capabilities, and that the cumulative integration of these technologies leads to measurable improvements in efficiency, visibility, and decision-making agility.

To address these questions and hypotheses, the research employs a qualitative, interpretive methodology rooted in systematic literature review. Academic papers, industry reports, and authoritative reviews were collected with a focus on topics such as transport logistics digitalization, Industry 4.0, IoT applications in logistics, artificial intelligence in logistics, and supply chain visibility. The collected literature was analyzed thematically to identify key technological enablers, including computerized route planning, telematics, IoT, geospatial tracking, AI, and automation, and to examine their impacts on logistics performance in terms of efficiency, visibility, responsiveness, and resilience.

This thematic analysis supported the development of four coherent stages of digital transformation in logistics, each stage defined by the integration of specific technologies and corresponding operational improvements. The resulting conceptual model illustrates the cumulative and integrative nature of these technological changes, offering a structured framework for understanding the progressive transformation of logistics systems.

The methodological approach aligns with prior research that uses generational modeling and thematic review to describe technological change in logistics. For example, [1] provides a staged analysis of IT adoption in maritime transport, while [12] offers an industry-focused examination of Logistics 4.0 technologies and their strategic implications. Studies such as [18] and [11] similarly apply structured literature reviews to map innovation diffusion and technological impacts in supply chains.

Results and further discussions

The main result of this research is a conceptual model that organizes the digital transformation of transport logistics into four coherent stages: Digitalization 1.0 (computerized route planning), 2.0 (IoT and telematics-based monitoring), 3.0 (geospatial tracking and real-time visibility), and 4.0 (AI-driven, integrated, and autonomous systems). This staged model captures the cumulative nature of technological integration in logistics operations, highlighting how successive waves of innovation build upon previous capabilities to deliver improved efficiency, visibility, responsiveness, and resilience. To support the proposed conceptual framework, Table 2 maps the main digitalization technologies across stages and highlights their cumulative impact on logistics capabilities.

Table 2: Mapping of Digitalization Stages to Key Logistics Capabilities.

Capability	Digitalization 1.0	Digitalization 2.0	Digitalization 3.0	Digitalization 4.0
Efficiency	Route optimization	Telematics, IoT	-	AI, automation
Visibility	-	-	Geospatial platforms	Integrated tracking, digital twins
Responsiveness	-	Cloud integration	AI-based rerouting, autonomy	Predictive analytics, real-time decision support

Resilience	-	-	-	Disruption anticipation, self-adaptive logistics
Sustainability	-	-	-	Emission monitoring, green optimization algorithms

Source: Authors' own research.

Critically examining these results shows that this framework helps explain not only what technologies have been adopted in logistics but also how their integration transforms operational and strategic decision-making. The progression from manual route planning to AI-driven, adaptive systems marks a shift from static, reactive logistics to dynamic, predictive, and even autonomous management. This interpretation aligns with prior work such as [1], who similarly identify generational IT adoption patterns in maritime logistics, but this paper extends their generational model by explicitly structuring the evolution across the broader transport logistics sector.

Compared to industry-oriented frameworks like those presented by [12], which emphasize emerging Logistics 4.0 technologies such as blockchain and digital twins, this paper's model clarifies the sequence and cumulative dependencies among these innovations. For instance, real-time geospatial tracking (3.0) is a necessary precondition for effective AI-driven dynamic routing and predictive maintenance (4.0). Likewise, the integration of IoT data in stage 2.0 enables the big-data environment required for stage 4.0 machine learning applications.

The proposed framework also contributes to existing academic discussions on innovation diffusion in logistics by offering a structured typology that can inform both empirical studies and practical planning. Logistics firms can use this model to assess their own digital maturity, identify gaps in technology adoption, and develop roadmaps for transformation aligned with industry best practices.

Nevertheless, it is important to recognize certain limitations. While the model is grounded in an extensive literature review, it remains conceptual and does not include new empirical measurements or industry case-study validation. Future research should test this staged framework quantitatively, for example by surveying logistics firms to map actual adoption patterns, or by modeling cost and efficiency gains associated with each stage.

In practical terms, the model has clear applications. For policymakers, understanding the cumulative nature of digital transformation can help guide infrastructure investment (e.g., supporting connectivity and data interoperability). For logistics managers, it offers a roadmap for technology investment decisions. For researchers, it provides a basis for hypothesis testing about technology impacts on supply chain performance.

Conclusion

This study examines the digital transformation of transport logistics through the development of a four-stage conceptual framework, progressing from Digitalization 1.0 to 4.0. Drawing on a structured literature review and thematic synthesis, the research identified key enabling technologies at each stage and analyzed their cumulative impact on operational efficiency, supply chain visibility, responsiveness, and resilience.

The main contribution of this paper consists in the articulation of a coherent, sequential model that integrates disparate technological developments into a unified perspective. By distinguishing between the successive phases of digital adoption, from basic computerized route planning (1.0), through telematics and enterprise connectivity (2.0), to geospatial tracking and IoT-based visibility (3.0), and finally to AI-driven, autonomous logistics systems (4.0), the framework offers a structured understanding of technological evolution within the transport and logistics sector. This approach responds to existing gaps in the literature, where digital technologies are often analyzed in isolation rather than as part of an integrated transformation process.

From a practical standpoint, the model can serve as a diagnostic and planning tool for logistics firms, enabling them to assess their current stage of digital maturity and to identify future directions for strategic investment. It also holds implications for policymakers and infrastructure stakeholders, who may use the findings to support informed decisions regarding digital infrastructure, data interoperability, and innovation funding.

Future research is needed to empirically test the proposed framework, evaluate the adoption trajectories across different regions and industries, and quantify the performance benefits associated with each stage. Comparative studies between firms or supply chains at different stages of digital maturity could further substantiate the model's explanatory and predictive value.

In conclusion, the digital transformation of transport logistics should be understood not as a singular leap, but as a cumulative and staged process. Recognizing these stages and their interdependencies provides a more comprehensive basis for academic inquiry and supports the development of informed strategies for technology adoption and organizational change in logistics systems.

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