

QUALITY ASSURANCE FOR INDUSTRY 5.0 LOGISTICS NETWORKS

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Abstract: Collaborative logistics networks are increasingly adopted to improve efficiency, resilience, and sustainability in complex supply chain environments. However, ensuring consistent service quality across organizational boundaries remains a critical challenge, as traditional quality assurance approaches are predominantly firm-centric and insufficient for networked logistics systems. At the same time, the ongoing digital transformation of logistics and the emergence of Industry 5.0 call for integrated quality management approaches that combine advanced digital technologies with human-centric governance principles. This paper develops a conceptual framework for digital quality assurance in collaborative logistics networks from a network-level and socio-technical perspective. Based on a PRISMA-guided systematic literature review, the study synthesizes research on logistics quality management, digitalization, collaborative network governance, and Industry 5.0. The proposed framework integrates five interrelated layers: data acquisition and quality sensing, digital quality analytics, human–digital decision support, governance and trust mechanisms, and sustainability and resilience integration. The framework conceptualizes quality assurance as a network-level capability emerging from coordinated data sharing, interpretable analytics, and human-in-the-loop decision-making supported by transparent governance structures. The study contributes by providing an integrated conceptual architecture that extends quality management beyond firm-level boundaries and by demonstrating its practical applicability in collaborative logistics contexts. The findings offer guidance for designing proactive, transparent, and resilient quality assurance mechanisms in digitally connected supply networks.

Keywords: Digital quality assurance; collaborative logistics networks; Industry 5.0; supply chain quality management; network governance; human-in-the-loop decision-making; digital transformation

1. INTRODUCTION

Collaborative logistics networks have become a defining feature of contemporary supply chain systems. By enabling resource sharing, coordinated distribution activities, and joint infrastructure utilization, such networks contribute to improved efficiency, enhanced flexibility, and increased resilience in increasingly complex and uncertain operating environments [1-2]. As digital technologies continue to reshape logistics processes, collaboration among multiple autonomous actors is no longer an exception but a structural characteristic of modern supply chains [3]. At the same time, the growing interdependence among logistics actors introduces new managerial challenges. One of the most critical among these is the assurance of consistent service and process quality across organizational boundaries. Traditional approaches to quality assurance in logistics and supply chain management have been developed primarily within the context of individual firms and internally controlled processes [4-5]. In collaborative logistics networks, however, service performance emerges from the interaction of multiple organizations, shared digital infrastructures, and distributed decision-making processes [6]. As a result, firm-centric quality management frameworks are often insufficient to capture and govern quality in such

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environments. The ongoing digital transformation of logistics further complicates this challenge while simultaneously offering new opportunities. Technologies such as IoT-based sensing, real-time data analytics, and digital coordination platforms enable unprecedented visibility into logistics operations [1, 7-8]. These developments make it possible to monitor, analyse, and respond to quality-related events across organizational boundaries. However, technological capabilities alone do not guarantee effective quality assurance. Without appropriate governance structures and decision-making mechanisms, increased data availability may even amplify coordination problems rather than resolve them [9]. In parallel, the emergence of the Industry 5.0 paradigm highlights the importance of integrating technological advancement with human-centric, ethical, and sustainability-oriented principles [10-11]. Within this perspective, digital systems are expected not only to enhance efficiency but also to support transparency, accountability, and responsible decision-making. For quality assurance in collaborative logistics networks, this implies that effective solutions must combine data-driven analytics with governance mechanisms and human-in-the-loop decision processes. Despite the growing relevance of collaborative logistics systems, the existing literature provides limited guidance on how quality assurance can be conceptualized and structured at the network level. Prior research has often addressed quality management, digital technologies, collaborative logistics, and governance mechanisms as separate domains [5, 7, 9]. Therefore, there is a lack of integrative frameworks that capture how these elements interact in digitally enabled, multi-actor logistics environments.

This study addresses this gap by developing a conceptual framework for digital quality assurance in collaborative logistics networks. The framework adopts a socio-technical and network-oriented perspective, conceptualizing quality assurance as an inter-organizational capability that emerges from coordinated data sharing, digital quality analytics, human-digital decision support, and governance structures. By integrating insights from logistics management, digital transformation research, and network governance theory, the study provides a structured foundation for understanding and designing quality assurance mechanisms in Industry 5.0 logistics systems. This study makes three main contributions. First, it reconceptualizes quality assurance as a network-level capability in collaborative logistics systems, extending existing firm-centric perspectives. Second, it develops an integrated digital quality assurance framework that combines data-driven analytics, governance mechanisms, and human-centred decision processes within a unified architecture. Third, it demonstrates the practical relevance of the framework through an illustrative application in a multi-actor logistics scenario, highlighting its potential to support coordinated and proactive quality management.

2. LITERATURE REVIEW METHODOLOGY: PRISMA-BASED APPROACH

A systematic literature review was conducted following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines in order to ensure a transparent, structured, and reproducible selection process (Fig. 1). The objective of the review was to identify and synthesize relevant contributions at the intersection of logistics and supply chain management, quality management, digital transformation, collaborative logistics networks, and Industry 5.0.

The literature search was performed using two major scientific databases, Scopus and the Web of Science Core Collection. These databases were selected due to their broad coverage of peer-reviewed journals in logistics, operations management, and industrial engineering, as

well as their complementary indexing structures, which help reduce the risk of systematic bias in literature identification. The search strategy combined several keyword clusters reflecting the core conceptual domains of the study. These included digital quality management (e. g. “digital quality assurance”, “digital quality management”), collaborative logistics structures (e. g. “collaborative logistics”, “collaborative supply chain”), governance mechanisms in logistics networks, and emerging Industry 5.0-related concepts [3, 7, 10]. The search strings were iteratively refined to capture relevant variations of these terms while maintaining conceptual precision. The search was limited to publications published between 2010 and 2025, reflecting the period during which digital supply chain technologies, network-oriented logistics models, and Industry 4.0 and Industry 5.0 paradigms have become increasingly prominent [3, 8, 10]. To ensure both relevance and academic rigor, explicit inclusion and exclusion criteria were defined prior to the screening process.

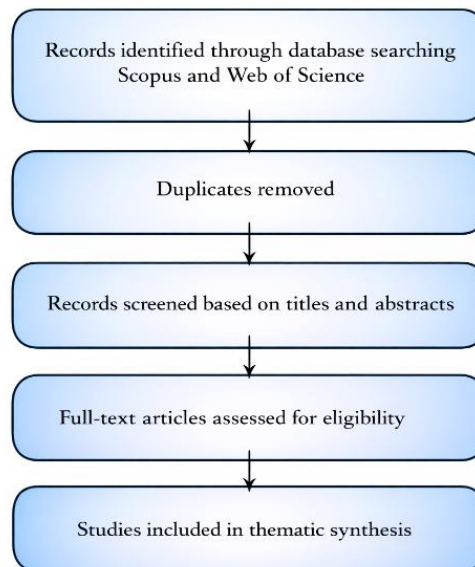


Figure 1. Systematic literature review process based on PRISMA methodology

The review focused exclusively on peer-reviewed journal articles published in English. Studies were included if they addressed logistics or supply chain contexts and explicitly engaged with at least one of the following themes: quality management, digitalization of logistics processes, collaborative network structures, or governance mechanisms. Publications were excluded if they were non-peer-reviewed (e.g., conference proceedings or book chapters), purely technical or algorithmic without relevance to quality management or organizational coordination or focused exclusively on intra-organizational quality systems without considering inter-organizational or network-level dynamics. The literature identification and selection process followed the standard PRISMA workflow [12]. The initial database search yielded 1,284 records. After the removal of 312 duplicate entries, 972 publications remained for screening. In the first stage, titles and abstracts were reviewed to assess their relevance to the research scope, resulting in the exclusion of 643 records. The remaining 329 articles were subjected to full-text assessment. During this stage, additional

publications were excluded due to insufficient conceptual relevance, a purely technical focus, or the absence of inter-organizational or governance-related considerations. Following the full-text evaluation, a final set of 147 publications was retained for further analysis.

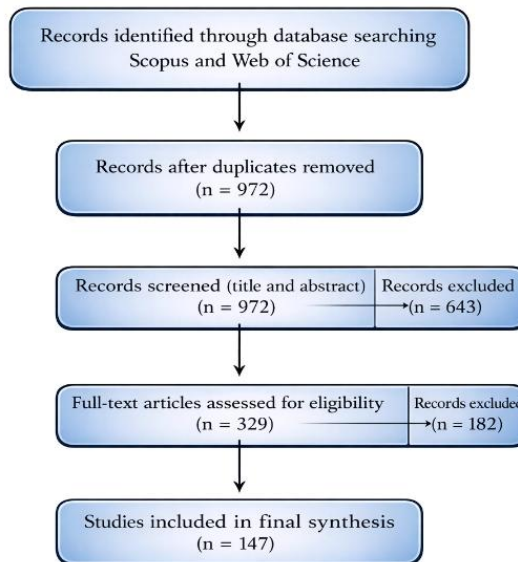


Figure 2. Systematic literature review process based on PRISMA methodology

The PRISMA flow diagram presented in Fig. 2 provides a structured overview of the identification, screening, eligibility, and inclusion stages, including the number of records retained and excluded at each step. This ensures transparency in the literature selection process and supports the reproducibility of the review. The selected body of literature was analysed using a thematic synthesis approach in order to identify dominant research streams and conceptual relationships across the reviewed studies [7, 9]. This analytical step aimed not only to classify existing research but also to reveal areas of conceptual overlap, fragmentation, and potential integration. Four primary thematic domains were identified: (i) quality assurance in logistics and supply chains, (ii) digitalization of quality management processes, (iii) collaborative logistics networks and their governance mechanisms, and (iv) human-centric perspectives associated with Industry 5.0 [5, 7, 10-11]. These thematic domains provide the conceptual foundation for the development of the proposed framework. By integrating insights from these research streams, the study establishes a coherent basis for conceptualizing digital quality assurance as a network-level capability in collaborative logistics environments.

3. RESEARCH QUESTIONS AND CONCEPTUAL POSITIONING

The primary objective of this study is to advance the theoretical understanding of quality assurance in collaborative logistics networks by developing a digitally enabled and Industry 5.0-oriented conceptual framework. While quality management has traditionally been studied within firm-level contexts [4-5], contemporary logistics systems increasingly operate as

inter-organizational networks in which multiple autonomous actors jointly contribute to service delivery and operational performance [1, 6]. In such environments, quality cannot be understood as the outcome of a single organization but emerges from coordinated interactions across organizational boundaries. At the same time, the ongoing digital transformation of logistics introduces both new opportunities and challenges for quality assurance. Technologies such as IoT-based sensing, real-time analytics, and digital platforms significantly enhance visibility across logistics processes [1, 7-8]. However, technological capabilities alone are insufficient to ensure reliable quality governance. Effective quality assurance in collaborative logistics networks requires the integration of digital infrastructures with governance mechanisms and human-centred decision-making processes [9]. From a theoretical perspective, this study positions digital quality assurance within a socio-technical and network governance framework. In this view, quality assurance is conceptualized as a network-level capability emerging from the interaction of data-driven analytics, institutional governance arrangements, and human decision-making. This perspective reflects the increasing importance of coordination, transparency, and shared accountability in digitally interconnected logistics systems [9]. Against this background, the study addresses the following research questions:

- RQ1: How can quality assurance be conceptualized as a network-level phenomenon in collaborative logistics systems?
- RQ2: Which technological and organizational components are required to support continuous and reliable quality monitoring across inter-organizational processes?
- RQ3: How can human-centric principles, such as accountability and interpretability, be integrated into digital quality assurance architectures in line with Industry 5.0?
- RQ4: Which governance mechanisms are necessary to align quality objectives and responsibilities among autonomous actors in collaborative logistics networks?

These research questions guide the conceptual development of the proposed framework. Rather than empirically testing causal relationships, the study aims to develop a theoretically grounded and structurally coherent model that integrates insights from logistics management, digital transformation research, and network governance theory. The resulting framework provides a foundation for future empirical validation, quantitative modelling, and decision-support applications in collaborative logistics environments.

4. CONCEPTUAL FRAMEWORK FOR DIGITAL QUALITY ASSURANCE IN COLLABORATIVE LOGISTICS NETWORKS

Fig. 3 presents the conceptual architecture of the proposed digital quality assurance framework for collaborative logistics networks. The framework adopts a network-level perspective and integrates technological, organizational, and governance dimensions within a socio-technical system logic [3, 9]. Rather than conceptualizing quality assurance as an isolated operational function, the framework interprets it as a coordinated capability emerging from interactions among digital infrastructures, governance mechanisms, and human decision-making processes across multiple organizations. In collaborative logistics environments, service performance is inherently interdependent and cannot be effectively managed through firm-level control mechanisms alone [4, 6]. Instead, it requires an integrated architecture that enables the continuous monitoring, interpretation, and coordination of quality-related information across organizational boundaries.

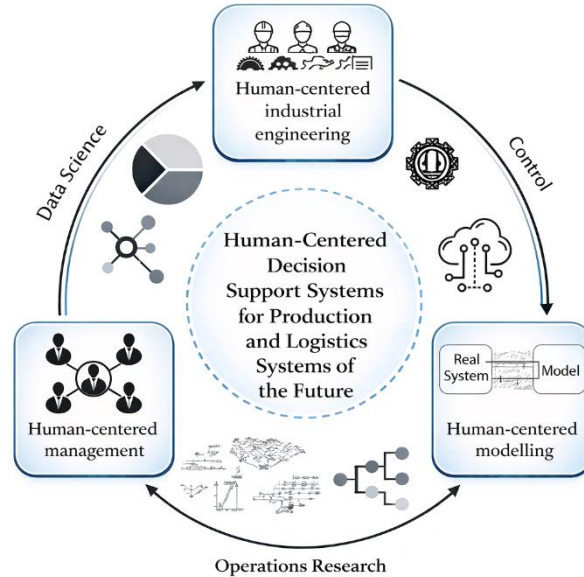


Figure 3. Conceptual framework of human-centred decision support systems in production and logistics

4.1. Design principles of the framework

The proposed framework is grounded in three core design principles reflecting both collaborative network governance theory and the Industry 5.0 paradigm [10-11]. First, the framework adopts a network-oriented perspective, recognizing that quality in collaborative logistics systems emerges from interdependencies among multiple autonomous actors rather than isolated organizational processes [6]. Service performance is therefore conceptualized as a network-level outcome resulting from coordinated activities across logistics service providers, transport operators, and digital platform participants. Second, the framework follows a socio-technical systems logic, emphasizing the interaction between technological infrastructures and organizational structures [9]. While digital technologies enable real-time monitoring, data integration, and predictive analytics, governance mechanisms and human decision-making processes ensure that these capabilities are effectively interpreted and translated into coordinated actions. Third, the framework aligns with the principles of Industry 5.0, emphasizing human-centricity, transparency, and resilience [10-11]. Instead of replacing human judgment with fully automated decision-making systems, the framework incorporates structured human-in-the-loop mechanisms that support accountable, context-aware, and ethically grounded quality management in digitally enabled logistics environments. Accordingly, the framework should not be interpreted as a prescriptive information technology architecture. Rather, it serves as a conceptual reference model that identifies the key functional components and interaction mechanisms required for effective digital quality assurance in collaborative logistics networks.

4.2. Framework structure and core components

The proposed framework consists of five interrelated layers that collectively capture the technological, organizational, governance-related, and human-centric dimensions of digital quality assurance in collaborative logistics networks. These layers form an integrated socio-technical architecture in which quality emerges as a network-level capability supported by coordinated data flows, analytical processes, decision-making mechanisms, and governance structures [3, 9]. The first layer, the data acquisition and quality sensing layer, provides the empirical foundation of the framework by capturing operational information in real time or near-real time. This layer integrates heterogeneous data sources generated across the logistics network, including Internet of Things (IoT) sensors, transportation management systems, warehouse management systems, telematics solutions, and digital coordination platforms [1, 7]. Quality-relevant data extend beyond conventional performance indicators such as delivery times or transport efficiency and include handling conditions, environmental parameters, service deviations, inter-organizational handover events, and exception signals indicating emerging quality risks. Due to the decentralized nature of collaborative logistics networks, data generation is inherently distributed, which introduces challenges related to interoperability, data ownership, reliability, and access rights. The second layer, the digital quality analytics and intelligence layer, transforms raw operational data into actionable insights. This layer includes analytical tools and artificial intelligence techniques capable of detecting anomalies, identifying patterns of service deviations, and predicting potential disruptions [7-8].

In contrast to traditional retrospective quality control approaches, the framework emphasizes anticipatory quality assurance, where predictive analytics enable early identification of quality risks before operational failures occur. A key requirement at this level is the transparency and interpretability of analytical models, as opaque algorithmic outputs may undermine trust and hinder coordinated action in multi-actor environments. The third layer, the human and digital decision support layer, represents the interface between analytical outputs and operational decision-making. In line with Industry 5.0 principles, this layer incorporates human-in-the-loop mechanisms, ensuring that automated insights are evaluated and contextualized by human actors [10-11]. Logistics planners, network coordinators, and quality managers interpret analytical signals, assess operational trade-offs, and coordinate corrective actions across organizational boundaries. Rather than replacing human judgment, digital technologies augment decision-making by providing relevant information, early warning signals, and structured analytical support.

The fourth layer, the governance and trust layer, ensures alignment and coordination among the autonomous actors participating in the collaborative logistics network. This layer defines the institutional arrangements, rules, and coordination mechanisms that support collective quality management [9]. It includes service level agreements, data-sharing protocols, performance monitoring systems, and conflict resolution mechanisms. Governance structures play a central role in assigning responsibilities, ensuring accountability, and facilitating coordinated responses to quality deviations. While digital technologies such as distributed ledger solutions or smart contracts may support transparency and traceability [17, 21], governance is primarily conceptualized as an organizational and institutional function supported by trust-building mechanisms and shared accountability structures. The fifth layer, the sustainability and resilience integration layer, extends the scope of quality assurance beyond short-term operational performance. Within this framework,

quality is interpreted as a broader capability that contributes to environmentally responsible, socially acceptable, and resilient logistics operations [5, 22]. This layer enables the integration of sustainability indicators - such as emissions, resource efficiency, and environmental compliance - into quality evaluation processes. At the same time, resilience-related dimensions, including system adaptability, disruption response capability, and recovery speed, are incorporated into decision-support mechanisms. Taken together, these five layers form a coherent and dynamically interacting system in which data captured at the sensing level feed into analytical processes, which generate insights for human decision-makers and trigger coordinated governance responses across the network.

4.3. Interactions and system logic

The proposed framework is characterized by dynamic and bidirectional interactions among its components. Operational data captured at the sensing layer feed into analytical processes, which generate insights for human decision-makers. These decisions, in turn, influence governance arrangements, corrective interventions, and subsequent data interpretation processes across the network. Governance mechanisms define the rules under which data are shared, interpreted, and acted upon, while sustainability and resilience considerations shape both analytical priorities and decision-making criteria. This interaction logic enables continuous feedback loops that support proactive and coordinated quality management in collaborative logistics environments. By conceptualizing quality assurance as a network-level, socio-technical capability, the framework extends beyond traditional firm-centric approaches and provides a structured foundation for future empirical research, simulation-based analysis, and decision-support system development in digitally connected logistics systems [23].

5. FRAMEWORK VALIDATION AND EVALUATION

The objective of this section is not to empirically test causal relationships, but to evaluate the conceptual robustness and practical plausibility of the proposed digital quality assurance framework. Given the conceptual nature of the study, the framework is assessed through a structured evaluation approach that examines its theoretical consistency, internal coherence, and potential applicability in collaborative logistics environments. In conceptual research within logistics and supply chain management, newly developed frameworks are commonly evaluated through logical consistency checks, expert-informed reflection, and scenario-based reasoning prior to empirical testing [3, 9]. Following this tradition, the present study applies a qualitative multi-perspective evaluation strategy to examine whether the proposed framework provides a coherent and meaningful representation of digital quality assurance in collaborative logistics networks.

5.1. Validation strategy

The evaluation focuses on three complementary dimensions. First, conceptual validity concerns whether the framework adequately captures the structural characteristics and coordination challenges of collaborative logistics networks [6]. In particular, the framework is examined with respect to its ability to represent inter-organizational quality dependencies, distributed information flows, and decentralized decision-making processes. Second, internal

coherence refers to the logical consistency among the framework components. This dimension assesses whether the five layers of the framework form a structurally consistent architecture in which data acquisition, analytics, decision support, governance mechanisms, and sustainability considerations interact in a coherent manner. Third, practical relevance evaluates whether the framework provides meaningful guidance for addressing quality assurance challenges in real-world collaborative logistics systems. This dimension focuses on whether the framework supports decision-making, coordination, and governance processes across organizational boundaries. Together, these evaluation dimensions allow the framework to be examined not only as an abstract theoretical construct but also as a potential reference architecture for digital quality assurance in collaborative logistics environments.

5.2. Expert-based validation

To strengthen the conceptual robustness of the framework, insights from both academic literature and practitioner-oriented discussions in logistics and supply chain management are considered. Expert-informed reflection represents a common approach in conceptual research, allowing theoretical propositions to be assessed against practical experience and domain knowledge [3, 9]. In this context, the framework components are examined with regard to their relevance, completeness, and interpretability. Particular attention is given to the balance between digital technologies and human decision-making processes, the role of governance mechanisms in supporting network-level quality assurance, and the integration of Industry 5.0 principles such as transparency, accountability, and human-centric design [10-11]. This reflective assessment suggests that the proposed framework captures several critical dimensions of digital quality assurance that are frequently discussed separately in the literature but rarely integrated within a single conceptual architecture.

5.3. Illustrative application of the framework

To demonstrate the operational relevance of the proposed framework, this section introduces an illustrative application based on a representative collaborative logistics scenario. The example reflects a multi-actor logistics network in which several independent logistics service providers, distribution centres, and transport operators jointly coordinate urban and regional deliveries through a shared digital platform [1, 6]. Within this network, organizations exchange real-time operational data related to shipment status, handling conditions, and delivery performance. The network handles time-sensitive and condition-dependent goods, such as temperature-controlled products and high-value shipments, where service quality is critical and deviations may lead to significant operational, financial, or reputational consequences [4-5]. Despite the presence of digital tracking systems, the network experiences recurring quality-related challenges. These include inconsistencies in data reporting across actors, delays during inter-organizational handovers, variations in handling conditions during transport and storage, and limited transparency regarding the root causes of service disruptions. Additionally, the decentralized structure of the network complicates coordinated decision-making, as responsibilities for quality management are distributed among multiple actors [6-9]. This scenario illustrates a typical environment in which traditional firm-level quality assurance approaches are insufficient. Quality performance emerges from interactions across organizational boundaries and therefore requires a network-level perspective supported by integrated digital and governance mechanisms. The proposed

framework provides a structured approach to address these challenges by integrating real-time data sensing, digital quality analytics, human-centred decision-making, and governance structures. In the following section, the framework is applied step by step to this scenario in order to illustrate how its components support coordinated quality assurance in collaborative logistics networks.

5.4. Application of the framework

The application of the proposed digital quality assurance framework to the illustrative collaborative logistics scenario highlights how its five layers interact to support coordinated and proactive quality management across organizational boundaries. At the data acquisition and quality sensing layer, operational data are collected from multiple sources, including IoT sensors, transport management systems, warehouse systems, and digital coordination platforms [1, 7]. These data streams capture not only standard performance indicators such as delivery times, but also quality-relevant information such as temperature deviations, handling events, and anomalies occurring during inter-organizational handovers. The digital quality analytics and intelligence layer transforms these heterogeneous data inputs into actionable insights. Analytical tools and predictive models identify patterns of service deviations, detect anomalies, and generate early warning signals related to potential quality risks [7-8].

Importantly, the analytical processes are designed to remain interpretable, allowing participating actors to understand the logic behind identified risks. At the human and digital decision support layer, analytical outputs are integrated into decision-making processes involving logistics planners, quality managers, and network coordinators. Human-in-the-loop mechanisms ensure that automated insights are evaluated in context, taking into account operational constraints, trade-offs, and stakeholder priorities [10-11]. The governance and trust layer coordinates actions across the network by defining rules, responsibilities, and accountability structures [9]. Service level agreements, data-sharing protocols, and performance monitoring mechanisms provide a formal basis for collaborative quality management. When quality deviations are detected, governance mechanisms enable coordinated responses, such as initiating corrective actions, reallocating responsibilities, or revising operational procedures. Finally, the sustainability and resilience integration layer ensures that quality assurance is aligned with broader system-level objectives. In the illustrative scenario, this includes evaluating the environmental implications of corrective actions, as well as assessing the network's ability to respond to disruptions and maintain service continuity [5, 22, 24-26].

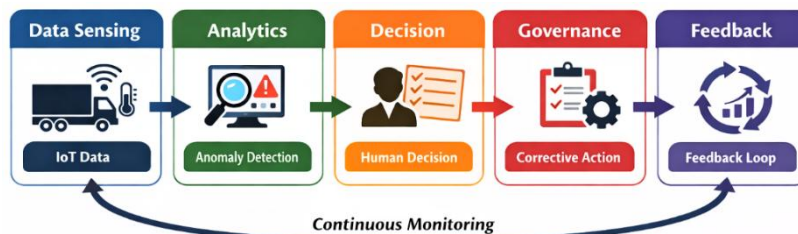


Figure 4. Application of the digital quality assurance framework in a collaborative logistics scenario

Overall, the application demonstrates that the framework enables a coordinated, multi-layered approach to quality assurance in collaborative logistics networks. By linking data sensing, analytics, decision-making, governance, and sustainability considerations, the framework supports a transition from reactive quality control toward proactive and network-oriented quality management. The operational logic of the proposed framework in a collaborative logistics context is illustrated in Fig. 4.

5.5. Validity, robustness, and limitations

While the present study provides a structured conceptual evaluation of the proposed framework, several limitations should be acknowledged. Conceptual validation cannot replace empirical investigation based on real operational data or observed network behaviour. In addition, the evaluation presented here focuses on logical coherence and theoretical plausibility rather than quantitative performance measurement. These limitations should therefore be interpreted as opportunities for future research. Empirical validation through case studies, simulation-based experiments, and quantitative modelling approaches represents a promising next step for assessing the operational effectiveness of digital quality assurance mechanisms in collaborative logistics networks.

6. DISCUSSION

This study addresses a critical gap in the logistics and supply chain management literature by reconceptualizing quality assurance as a network-level capability in collaborative logistics systems. While prior research has largely focused on firm-level processes [4-5], the increasing prevalence of inter-organizational logistics networks requires a broader perspective that captures distributed coordination, shared data infrastructures, and governance mechanisms [6, 9]. The findings of the literature review indicate that existing research remains fragmented across technological, organizational, and governance-oriented perspectives [7, 9]. By integrating these dimensions within a unified socio-technical framework, this study contributes to bridging previously disconnected research streams and provides a more comprehensive understanding of digital quality assurance in collaborative logistics environments. From a theoretical standpoint, the framework extends quality management beyond firm-level boundaries by conceptualizing quality as an emergent property of networked systems [6]. In this view, service performance depends on coordinated interactions among multiple actors rather than isolated organizational capabilities. The framework further highlights the importance of aligning digital infrastructures with governance mechanisms and human decision-making processes [9].

While digital technologies enable real-time monitoring and predictive analytics [7-8], their effectiveness depends on interpretability, accountability, and coordinated action across the network. The integration of Industry 5.0 principles strengthens this perspective by emphasizing human-centricity, transparency, and resilience [10-11]. The proposed framework demonstrates that digital quality assurance should not be understood as a purely technology-driven function, but as a socio-technical capability in which human judgment remains essential for ensuring responsible and context-aware decision-making. From a managerial perspective, the framework provides structured guidance for designing digital quality assurance systems in collaborative logistics networks. It highlights the need for interoperable data infrastructures, explainable analytical tools, and governance mechanisms

that align incentives and responsibilities among network actors [9]. In addition, the integration of sustainability and resilience considerations supports a transition toward more robust and adaptive logistics systems [5, 22]. Overall, the study demonstrates that effective quality assurance in collaborative logistics networks requires an integrated approach that combines technological capabilities, governance structures, and human-centred decision processes within a coherent system architecture.

7. CONCLUSION AND FUTURE RESEARCH DIRECTIONS

The increasing complexity and digital interconnectedness of logistics systems require a shift from firm-centric quality management toward network-oriented approaches [6, 9]. This study develops a conceptual framework for digital quality assurance that integrates technological infrastructures, governance mechanisms, and human-centred decision processes within a unified socio-technical architecture. By conceptualizing quality assurance as a network-level capability, the framework provides a structured basis for understanding how quality can be monitored, interpreted, and governed in collaborative logistics environments. The study contributes to the literature by integrating previously fragmented research domains and aligning quality management with the principles of Industry 5.0, including transparency, human-centricity, sustainability, and resilience [10-11]. Despite these contributions, the conceptual nature of the framework highlights the need for further empirical and analytical research. Future studies may operationalize the framework through quantitative modelling approaches, including multi-criteria decision-making methods and simulation-based analysis, to evaluate network-level quality performance under varying operational conditions.

In addition, the integration of digital twin technologies and real-time data environments offers promising opportunities for examining the dynamic interaction between quality monitoring and logistics operations [8]. Empirical validation through case studies and longitudinal research is also essential to assess the practical implementation of digital quality assurance mechanisms and to understand how governance structures, data-sharing arrangements, and organizational incentives influence their effectiveness. In conclusion, digital quality assurance represents a key enabler of reliable, transparent, and resilient collaborative logistics networks. Developing integrated, human-centred, and governance-aware quality management approaches will therefore be essential for the future evolution of digitally connected supply chain systems.

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Declaration of generative AI and AI-assisted technologies in the manuscript preparation process: During the preparation of this manuscript, the author used ChatGPT (OpenAI) to improve language clarity and stylistic quality. After using this tool, the author reviewed and edited the content as needed and takes full responsibility for the content of the published article.