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THE DIGITAL THREAD OF QUALITY: LINKING INCOMING INSPECTION DATA TO SUPPLIER PROCESS CONTROL FOR ZERO-DEFECT SUPPLY CHAINS

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ABSTRACT: Achieving zero-defect performance in contemporary supply chains remains a persistent challenge, particularly under conditions of outsourcing, multi-tier supplier networks, and limited visibility into upstream manufacturing processes. While incoming inspection is widely applied as a quality risk mitigation mechanism, it is frequently treated as a localized acceptance activity rather than as a strategic source of process intelligence. This paper addresses this limitation by examining how incoming inspection data can be systematically linked to supplier process control and governance through a Digital Quality Thread. Drawing on an integrative review of the quality management, supplier governance, inspection optimization, and digital quality assurance literature, the study synthesizes existing evidence into a coherent conceptual framework. The proposed framework positions incoming inspection as the primary measurement interface between buyers and suppliers and demonstrates how digitized and contextualized inspection data can be transformed into early-warning signals, predictive risk indicators, and governance-relevant performance inputs. These signals support supplier process control actions, performance evaluation, and incentive-compatible governance mechanisms aimed at defect prevention rather than reactive correction. The paper further highlights the enabling role of digital QA/QC platforms and traceability mechanisms in sustaining this closed-loop system across organizational boundaries. By linking inspection evidence to supplier accountability and decision-making, the Digital Quality Thread facilitates faster feedback, improved auditability, and coordinated quality management across complex supply chains. The main contribution of this study lies in integrating fragmented research streams into a unified framework that clarifies how incoming inspection can evolve from a gatekeeping function into a central driver of prevention-oriented, zero-defect supply chain management.
KEYWORDS: Digital quality thread, incoming inspection, supplier process control, supplier governance, zero-defect supply chains, quality traceability

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1. INTRODUCTION: ZERO-DEFECT SUPPLY CHAINS AND THE NEED FOR A DIGITAL QUALITY THREAD

Zero-defect quality is addressed in the literature not merely as an operational target, but as an organization-wide improvement philosophy embedded in structured quality management programs (Badri, 1995). In supply chains, this ambition is inherently linked to supplier quality management, since incoming quality reflects upstream process capability and the governance mechanisms that align supplier behavior with buyer requirements (Lee & Li, 2018). Empirical studies further show that supplier quality performance, including incoming inspection outcomes, is strongly associated with customer satisfaction and overall firm performance, confirming the strategic role of supplier-facing quality management beyond the receiving dock (Tracey & Tan, 2001; Chen, 2004; He, 2018).

Despite this recognition, incoming inspection is still predominantly used as a gatekeeping activity focused on acceptance or rejection decisions. Such an approach is insufficient for zero-defect supply chains. Research on opportunistic supplier behaviour demonstrates that certification alone does not guarantee conforming outputs, motivating buyers to rely on inspection and contingent payment mechanisms to deter quality risk (Babich & Tang, 2012). In addition, the effectiveness of inspection-based strategies depends on supply-chain structure, with multi-tier outsourcing altering the balance between inspection and downstream failure management (Dong, 2016). These findings indicate that zero-defect performance cannot be achieved through inspection intensification alone, but requires integrated, closed-loop quality governance across organizational boundaries.

This paper proposes the concept of a Digital Thread of Quality to address this gap. The digital thread is defined as a data-driven linkage connecting incoming inspection evidence with supplier process control, abnormality handling, and incentive-compatible governance mechanisms that support continuous improvement toward near-zero defects (ShangGuan, 2014; Lee & Li, 2018). Rather than merely digitizing inspection records, the digital thread transforms incoming inspection into an actionable signal for supplier process management and performance evaluation.

The objective of this study is to synthesize an evidence-based framework that explains how incoming inspection data can be systematically linked to supplier process control within zero-defect supply chains. The contribution is conceptual and integrative, positioning incoming inspection as a governance signal, emphasizing closed-loop feedback from detection to corrective action, and highlighting the role of incentives and supply-chain structure in making digital quality linkages effective.

2. INCOMING INSPECTION AS THE MEASUREMENT BACKBONE OF THE DIGITAL QUALITY THREAD

2.1 Limits of Traditional Incoming Inspection under Zero-Defect Objectives

Incoming inspection is the most prevalent mechanism for managing quality risk at the buyer-supplier interface and is widely treated as a central decision lever in sourced quality management (Chen, 2022; Lee & Li, 2018). In practice, however, incoming quality control (IQC) remains dominated by legacy sampling regimes and pass/fail judgment logic. The literature consistently highlights structural trade-offs between inspection cost, inspection accuracy, and residual defect risk, indicating that inspection intensification alone cannot ensure zero-defect performance (Zhou & Chen, 2025).

These limitations are amplified under zero-defect objectives, where defect rates are extremely low and traditional inspection struggles to generate statistically meaningful signals. Analytical work on acceptance sampling demonstrates that inspection outcomes are inseparable from the underlying sampling design, inspection accuracy, and stopping rules, and therefore cannot be interpreted in isolation as definitive indicators of supplier capability (Cudney, 2016).

2.2 Inspection Policy Intelligence: Sampling Design and Probabilistic Interpretation

To address the limitations of judgment-based inspection, the literature emphasizes the role of inspection policy intelligence in transforming incoming inspection results into interpretable quality evidence. Bayesian sampling plans and probabilistic inference models are explicitly motivated by the difficulty of detecting defects under low defective fractions, showing that inspection outcomes should be interpreted as evidence about supplier process risk rather than as binary conformity decisions (Hafeez, 2022). Recent optimization-based formulations of zero-defect incoming inspection further incorporate inspection inaccuracy and cost constraints, reinforcing the need to encode inspection context alongside inspection results (Zhou & Chen, 2025).

From a digital thread perspective, these findings imply that incoming inspection data must retain information about sampling assumptions and inference logic in order to support meaningful downstream analysis. Without this context, inspection data cannot reliably inform supplier process control or risk-based decision-making.

2.3 Digitized Measurement and Data enrichment for Supplier feedback

The quality signal generated by incoming inspection also depends on the fidelity and structure of measurement data. In electronics manufacturing, increasingly stringent IQC requirements have driven the adoption of machine vision systems that augment or replace manual inspection, improving repeatability and enabling richer defect characterization (Huang & Tsai, 2024). More broadly, quality control surveys distinguish incoming inspection from in-situ and post-process non-destructive testing, highlighting how digitized measurement modalities support tighter coupling between detection and control (Charalampous, 2020).

Evidence from in-situ monitoring studies further shows that continuous measurement improves process understanding and enables control schemes that link detection directly to corrective action, providing a conceptual parallel to buyer-supplier feedback loops based on incoming inspection data (Hafkamp, 2018). In supply chains such as batteries, unit-level non-destructive testing and continuous quality control are additionally linked to traceability and lifecycle assurance, illustrating how incoming inspection data can function as a persistent quality record beyond receiving (Ank, 2024).

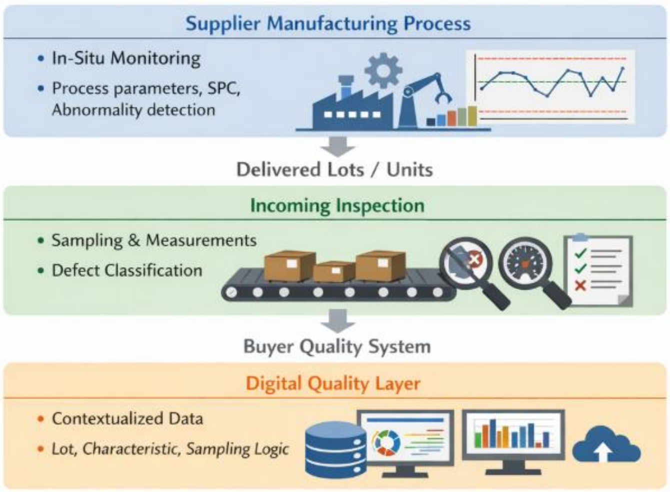

Figure 1. Quality control flowchart in production processes

Figure 1 illustrates incoming inspection as a measurement backbone that bridges supplier in-situ process behavior and buyer-side quality governance through digitized and contextualized inspection data.

3. FROM INCOMING INSPECTION TO SUPPLIER PROCESS CONTROL

3.1 From Judgment Inspection to Early Abnormality Detection

In conventional buyer-supplier settings, incoming inspection primarily serves a judgment function, confirming conformity or triggering rejection at receiving. While this approach protects downstream operations, it remains reactive and offers limited support for zero-defect objectives, where early detection of process drift is essential (ShangGuan, 2014).

The literature distinguishes two fundamentally different roles of incoming inspection:

- **Judgment-based inspection**, focused on acceptance or rejection decisions at receiving;
- **Abnormality-oriented inspection**, focused on identifying early warning signals of process instability.

Abnormality-oriented approaches integrate buyer-side warning limits with supplier-side abnormality handling mechanisms, enabling intervention before deviations propagate into systematic defects (ShangGuan, 2014). Case-based evidence further indicates that such inspection redesign improves material quality consistency, shortens process lead times, and enhances information exchange between buyers and suppliers, highlighting the relational value of inspection-driven feedback rather than stricter inspection alone (Iliescu, 2015).

3.2 Incoming Inspection as an Input to Supplier Performance Management

Incoming inspection outcomes are formally embedded in supplier performance management and evaluation systems. Supplier rating frameworks consistently include incoming inspection results alongside line reject rates, supplier service quality, and product reliability, with the explicit purpose of aligning supplier and manufacturer capabilities across the supply chain (Chen, 2004; He, 2018).

In practice, incoming inspection data supports several governance-relevant activities, including:

- supplier performance rating and segmentation;
- supplier selection, requalification, and escalation decisions;
- prioritization of supplier development and continuous improvement initiatives;
- evaluation of supplier involvement in design and improvement programs.

Empirical studies demonstrate that supplier quality performance and involvement, often triggered by such inspection-based signals, are positively associated with customer satisfaction and overall firm performance (Tracey & Tan, 2001). These findings reinforce the view that incoming inspection functions as a strategic governance signal rather than a purely operational metric.

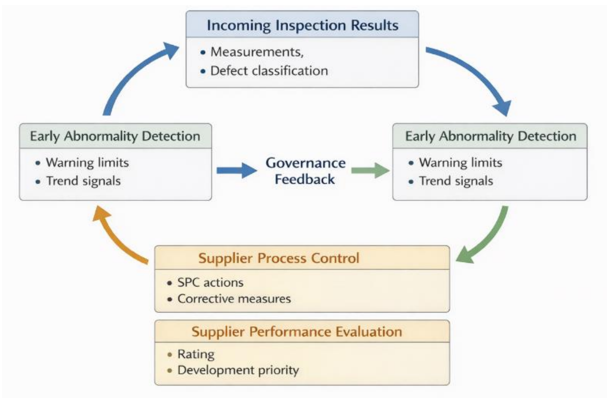

Figure 2. Feedback loop from incoming inspection to supplier process control

3.3 Predictive Interpretation of Inspection Outcomes for Supplier Process Control

To support proactive supplier process control, incoming inspection results must be interpreted in a forward-looking manner. Under zero-defect ambitions, extremely low defect fractions limit the informational value of binary inspection outcomes, motivating the use of probabilistic and predictive models.

Analytical approaches proposed in the literature include:

- **Markov-based acceptance prediction models**, used to estimate supplier acceptance probabilities and regulate supplier selection while reducing quality-related costs (Mani, 2021);
- **Bayesian sampling and inference methods**, designed to support decision-making when inspection evidence is limited and defect rates are very low (Hafeez, 2022);
- **Optimization-based sampling design models**, which explicitly account for inspection inaccuracy and cost constraints in incoming quality control (Cudney, 2016; Zhou & Chen, 2025).

Together, these approaches transform incoming inspection data from retrospective defect records into predictive estimates of supplier process capability and quality risk, enabling earlier and more targeted supplier interventions.

4. GOVERNANCE AND INCENTIVES

4.1 Inspection Data in Supplier Governance

Incoming inspection data becomes strategically relevant only when it informs supplier governance rather than remaining confined to operational decision-making. The supplier quality management literature emphasizes that inspection outcomes gain leverage when they influence how suppliers are evaluated, differentiated, and supported over time (Lee & Li, 2018). Within this perspective, incoming inspection functions as a structured signal that guides managerial attention and resource allocation.

From a governance standpoint, inspection data is commonly used to support:

- supplier performance rating and segmentation;
- prioritization of supplier development and improvement initiatives;
- escalation of surveillance intensity for high-risk suppliers or characteristics;
- adjustment of prevention-oriented versus detection-oriented quality controls.

This role is consistent with broader quality management research identifying supplier quality management as a critical factor for organization-wide improvement programs, including zero-defect initiatives (Badri, 1995). When embedded in a digital quality thread, inspection results are therefore transformed into repeatable and auditable governance inputs.

4.2 Incentive Mechanisms Based on Inspection Results

Governance effectiveness depends not only on visibility but also on incentives. Several studies demonstrate that inspection alone is insufficient to influence supplier behavior under information asymmetry or opportunistic conditions; inspection outcomes must be linked to incentive-compatible mechanisms that affect supplier decision-making (Babich & Tang, 2012).

The literature identifies multiple incentive mechanisms that can be activated using incoming inspection and traceability data:

- **Investment-incentive-inspection portfolios**, balancing buyer investment, supplier effort incentives, and inspection intensity (Lee & Li, 2018);
- **Defect penalties and purchase-price adjustments**, enabled by inspection and quality tracing mechanisms (Huang, 2011);
- **Deferred payment schemes**, contingent on defect discovery, used to discourage quality shirking (Babich & Tang, 2012);
- **Recall cost-sharing and warranty arrangements**, allocating downstream failure responsibility based on inspection evidence and attribution accuracy (Chao, 2009; Balachandran & Radhakrishnan, 2005).

Table 1. Linking incoming inspection results to supplier governance mechanisms

Incoming inspection result	Governance action	Expected supplier response
Recurrent defects	Escalation, penalties	Process correction
Stable quality performance	Reduced inspection, incentives	Capability sustainment
High-risk characteristics	Buyer investment, SPC requirements	Process stabilization
Traceable nonconformities	Cost sharing, warranty allocation	Prevention focus

By linking inspection outcomes to these instruments, the digital quality thread ensures that quality deviations trigger not only corrective actions but also economic signals that motivate sustained supplier process improvement.

4.3 Governance in Multi-Tier Supply Chains

The importance of inspection-driven governance increases as supply chains become more complex. In multi-tier and outsourced supply networks, buyers often have limited direct visibility into upstream processes, increasing reliance on inspection-based signals. Research shows that the relative effectiveness of inspection-based quality management depends on supply-chain structure, with multi-level networks requiring stronger coupling between inspection and governance than dyadic relationships (Dong, 2016).

Empirical studies further indicate that incoming inspection remains the most prevalent quality risk mitigation strategy under financial pressure and outsourcing, while supplier quality choices are strongly influenced by contract parameters and governance design (Chen, 2022). In this context, a digital quality thread enables inspection evidence to propagate upstream, supporting accountability and coordinated quality control across multiple supply-chain tiers.

5. DIGITAL ENABLERS AND TRACEABILITY

The effective linkage between incoming inspection and supplier process control relies on digital enablers that ensure structured data capture, rapid interpretation, and cross-boundary visibility. The literature on quality digitalization emphasizes that digital tools enhance, rather than replace, established quality management practices by improving data integrity, timeliness, and auditability (Prodhan, 2022).

Digital QA/QC platforms and dashboards support the transformation of incoming inspection from fragmented records into structured quality evidence. By enabling standardized data capture, trend visualization, and early warning of deviations, such platforms facilitate faster escalation and more consistent communication of inspection results to internal stakeholders and suppliers (Hidayat, 2025). Advanced analytics and AI-based techniques further strengthen defect detection and anomaly identification when applied to digitized inspection data streams (Prodhan, 2022).

Traceability complements these capabilities by linking inspection outcomes to specific lots, units, or process conditions, enabling attribution of responsibility and targeted corrective action. Mechanism design studies explicitly combine incoming inspection and quality tracing to support accountability and incentive mechanisms in supplier relationships (Huang, 2011). In emerging contexts such as battery supply chains, unit-level quality control and traceability are also associated with lifecycle assurance and regulatory requirements, illustrating the broader governance role of inspection data (Ank, 2024).

6. AN INTEGRATED DIGITAL QUALITY THREAD FRAMEWORK

This section presents an integrated framework that explains how incoming inspection data can be transformed into a continuous driver of supplier process control and governance in zero-defect supply chains. The framework does not introduce new tools or mechanisms; instead, it clarifies how the elements discussed in the previous sections interact as a coherent, closed-loop system.

The proposed digital quality thread is built around four interconnected components, each with a distinct role in the prevention-oriented management of supplier quality.

6.1 Incoming Inspection as the Measurement Layer

Incoming inspection represents the primary interface between buyer and supplier and acts as the sensing point of the framework. At this stage, quality information is generated through measurements, defect classification, and trend observation.

Within the digital quality thread, incoming inspection provides:

- structured and contextualized quality evidence;
- early indications of process instability at the supplier;
- a common reference point for technical and managerial decisions.

Rather than serving only acceptance or rejection decisions, incoming inspection becomes the starting point of continuous quality feedback.

6.2 Abnormality Detection and Supplier Process Control

Inspection data is subsequently interpreted to identify abnormal patterns, trends, or deviations from expected performance. Through warning limits, trend analysis, and probabilistic interpretation, incoming inspection results are transformed into actionable signals.

These signals trigger supplier-side responses such as:

- containment actions;
- SPC adjustments;
- corrective and preventive measures at process level.

This step shifts quality management from reactive defect handling to early intervention and prevention.

6.3 Supplier Governance and Incentives

The same inspection-derived signals also feed supplier governance mechanisms. Performance trends observed at incoming inspection inform how suppliers are evaluated, prioritized, and supported over time.

In the framework, incoming inspection data supports:

- supplier performance differentiation and rating;
- prioritization of supplier development actions;
- activation of incentive or penalty mechanisms based on evidence.

By linking inspection results to governance and incentives, the digital quality thread ensures that quality deviations have managerial and economic consequences, not only technical ones.

6.4 Digital Enablers and Traceability

Digital platforms and traceability infrastructure enable the framework to operate consistently across organizational boundaries. Digital QA/QC systems support standardized data capture and visualization, while traceability mechanisms link inspection evidence to specific lots, units, and supplier processes.

These enablers provide:

- data integrity and auditability;
- reduced latency between detection and action;
- continuity of quality information over time.

Digitalization thus sustains the feedback loop rather than acting as an isolated technological layer.

6.5 Integrated Closed-Loop Operation

As illustrated in Figure 3, the digital quality thread operates as a closed-loop system in which:

- incoming inspection functions as the measurement layer;
- supplier process control provides technical response;
- governance and incentives drive behavioral alignment;
- digital enablers ensure reliability and continuity.

By maintaining these linkages, organizations can move beyond defect detection at receiving toward coordinated, prevention-oriented quality management across complex supply chains.

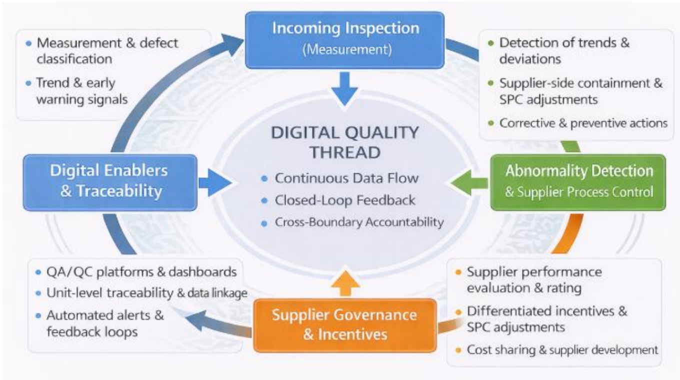

Figure 3. Integrated digital quality thread

7. CONCLUSIONS AND IMPLICATIONS

This paper addressed the challenge of achieving zero-defect performance in supply chains by examining how **incoming inspection data** can be systematically linked to **supplier process control and governance mechanisms** through a digital quality thread. Rather than treating inspection as a localized acceptance activity, the study positions incoming inspection as a strategic interface between buyers and suppliers, capable of supporting prevention-oriented quality management when properly integrated.

A central conclusion is that **incoming inspection remains indispensable**, particularly in complex and outsourced supply chains, but its effectiveness is fundamentally limited when used in isolation. Pass/fail inspection logic provides protection against downstream defects but offers little insight into upstream process behaviour. The literature reviewed consistently shows that inspection data gains strategic value only when interpreted as a signal of supplier process stability and risk, rather than as a binary conformity outcome.

By synthesizing research on inspection design, abnormality detection, supplier performance management, governance mechanisms, and digital quality infrastructure, this paper proposed an **integrated Digital Quality Thread framework**. Within this framework, incoming inspection functions as the sensing layer, abnormality detection and SPC as the corrective layer, governance and incentives as the behavioural alignment layer, and digital platforms and traceability as the enabling infrastructure. The interaction of these layers forms a closed-loop system in which detection, response, and learning are continuously connected.

From a theoretical perspective, the study contributes by **bridging fragmented research streams** that are often treated separately in the literature. Inspection optimization and sampling theory, supplier quality management, mechanism design, and digital quality systems are integrated into a single conceptual structure. This synthesis clarifies how inspection evidence can simultaneously support technical process control and managerial decision-making, reinforcing the view that quality management in supply chains is inherently socio-technical.

From a practical standpoint, the findings have several implications for organizations pursuing zero-defect objectives. First, firms should design incoming inspection not only to protect internal processes but also to generate **early-warning signals** that can be shared with suppliers. This requires contextualized inspection data, including sampling logic, inspection accuracy assumptions, and trend analysis, rather than isolated defect counts. Second, inspection results should be explicitly embedded into **supplier governance routines**, such as performance rating, escalation criteria, and supplier development prioritization, to ensure consistency and transparency.

Third, the study highlights that **incentive alignment is critical**. Inspection-driven feedback alone may not lead to sustained supplier improvement unless it is coupled with incentive-compatible mechanisms, such as investment decisions, penalties, cost-sharing arrangements, or deferred payments. When inspection outcomes have economic and contractual consequences, suppliers are more likely to invest in prevention and process capability rather than short-term compliance.

Fourth, the role of **digital enablers and traceability** is emphasized as foundational rather than optional. Digital QA/QC platforms, dashboards, and traceability mechanisms reduce latency from detection to action, improve auditability, and allow inspection evidence to persist over time and across organizational boundaries. Importantly, digitalization is most effective when aligned with existing quality governance structures, avoiding technology-driven implementations that are disconnected from decision-making logic.

Despite its contributions, this study has limitations. The framework is conceptual and grounded in prior empirical and analytical research, but it has not been empirically validated within a single industrial case or across multiple supply-chain contexts. Future research should therefore focus on **longitudinal case studies** and **quantitative validation** to assess the performance impact of inspection-to-SPC feedback loops, particularly under very low defect rates characteristic of zero-defect ambitions. Additional work is also needed to examine governance and incentive mechanisms in **multi-tier supply chains**, where attribution of responsibility and data sharing become more complex.

In conclusion, the Digital Quality Thread framework provides a structured way to rethink the role of incoming inspection in modern supply chains. By connecting inspection data to supplier process control, governance, and digital infrastructure, organizations can move beyond reactive defect detection toward coordinated, prevention-oriented quality management. This shift is essential for sustaining zero-defect performance in increasingly complex and data-intensive supply networks.

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